Consolidated Report

of

National Fellow Project

on

Assessing soil quality key indicators for development of soil quality index using latest approaches under predominant management practices in rainfed agro-ecology Code: 803105

(Revised title in SRC: Restoration of soil quality through conservation agricultural management practices and it's monitoring using Integrated Soil Quality Index (ISQI) approach in rainfed production system (s))

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Executive Summary

1) Out of the vast acreage of 142.2 million ha net cultivated area, about 95.5 million ha lands depends on rain contributing about 44% of the total food production in the country. National statistics reveal that rainfed agriculture supports about 40% of the India's more than 1000 million population. Major portion of the coarse cereals (91%), pulses (91%), oilseeds (80%) and cotton (65%) are grown in these moisture stressed regions thus, emphasizing the important role played by rainfed agriculture in the country's economy and food security. After an era of green revolution, lot of efforts have gone into the development of necessary farm-inputs such as development of good seeds, enhanced production of fertilizers, insecticides and pesticides and development of water resources and irrigation potential. The benefits of these initiatives have not gone significantly to the rainfed land holders. In the country as a whole, there are about 120 million land holdings. Out of these, about 63.0 % are marginal (< 1 ha size), 18.9 % are small (1-2 ha), 11.7 % are small to medium (2-4 ha), 5.4% are medium (4-10 ha) and only 1.02 % are large (> 10 ha). Whereas, of the 97 million farm holders in rainfed regions, 76 % are small (< 2 ha) and marginal cultivating only 29 % of the unconsolidated and scattered arable land.
2) Besides climatic and edaphic constraints, the investment capacity of small holders towards agriculture is very low which leads towards miserably low yields and degraded soil resource. It has been reported that only 9% of the districts in India use more than 200 kg of $N + P_2O_5 + K_2O$ per hectare (Tiwari, 2006). On the other end, only 32 % districts used < 50 kg fertilizer nutrients / ha ($N + P_2O_5 + K_2O$) per hectare. Most of the rainfed regions fall in this category. The average fertilizer use in the country as a whole in the recent years, varied between 90-104 kg ha^{-1} which is very low when compared with the neighboring countries, like China (277.7 kg ha^{-1}), Japan (290.6 kg ha^{-1}) and Korea Republic (409.7 kg ha^{-1}). At the same time, the yield levels of some of the crops such as paddy, wheat maize, etc., in India are significantly lower compared to these countries. Hence, apart from many other reasons, low fertilizer use in India is definitely one of the important causes of low yields. The average yield level of coarse cereals in some of the rural farms is still much lower (370 kg $ha^{-1)}$) than it should be. Apart from moisture limitations, rainfed areas are also at disadvantageous position because of low soil organic matter content and poor soil fertility and overall deterioration in soil quality and its poor resilience. The predominant reasons of land degradation and deterioration in soil quality in these regions could be as follows:

- Loss of top soil and organic matter associated with clay size fractions due to water erosion resulting in a 'big robbery in soil fertility'.
- Intensive deep tillage and inversion tillage with moldboard and disc plough resulting in i) fast decomposition of remnants of crop residues which is further catalyzed by high temperature, ii) disintegration of stable soil aggregates and enhanced rate of oxidation of entrapped organic C and iii) disturbance to the habitat of soil micro flora and fauna and loss in microbial diversity
- Dismally low levels of fertilizer application as stated above and widening of plant nutrient removal-use gap
- Mining and other commercial activities such as use of top soil for other than agricultural purpose
- Mono cropping without following any suitable rotation
- Nutrient imbalance caused due to disproportionate use of primary, secondary and micronutrients
- No or low use of organic manures such as FYM, Compost, Vermi-compost and poor recycling of farm based crop residues because of competing demand for animal fodder. The reduction in the number of draught cattle due to mechanization has further aggravated the scarcity of dung available for preparation of compost/manures
- No or low green manuring as it competes with the regular crop for date of sowing and other resources in rainfed regions
- Poor nutrient use efficiency attributing to nutrient losses due to leaching, volatilization and denitrification
- Indiscriminate use of other agricultural inputs such as herbicides, pesticides, fungicides, etc., resulting in poor soil and water quality
- Water logging, salinity, alkalinity and development of acid soils

Consequent to the above, mentioned reasons, soils encounter diversity of constrains on account of physical, chemical and biological soil health and ultimately end up with poor functional capacity (soil quality) resulting into low productivity. To reverse some of the above adversaries of soil degradation, there is no other way than to focus on effective land protection and soil quality restoration and improvement measures. Some of the measures such as conservation agriculture practices viz., reduced tillage, surface residue application, green manuring, integrated use of organic and inorganic source of nutrients, non-pesticidal insect management, balanced fertilizer application with special emphasis on limiting nutrients, enhancement of fertilizer doses according to targeted yields and crop removal rates could be effective in protecting the land from further degradation and in improvement and restoration of soil quality. In rainfed agro-ecosystem, various soil-nutrient management practices are being experimented for last many years at experimental stations of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) under different soil types, varying climatic conditions in different cropping systems. Besides these, farmers are also following different level of management at their farms. Some of these practices are quite beneficial and aggradative in nature, whereas, others are degradative.

Thus, keeping in view the above and to monitor the aggradative and degradative practices and to identify the key indicators of soil quality to compute Soil Quality Indices for different management practices and situations (soil type, climate, cropping systems, etc.) across the country, the present study entitling **"Assessing soil quality key indicators for development of soil quality index using latest approaches under predominant management practices in rainfed agroecology"** was under taken under National Fellowship Program from 2005 to 2010 with the following objectives :

Objective 1: To evaluate the long term influence of existing selected soil and nutrient management practices on soil quality parameters, to identify the key indicators and to compute the soil quality indices under different cropping systems in rainfed areas across the country.

Objective 2: To evaluate the low-cost integrated nutrient management (INM) treatments (comprising of farm based organics) under conventional and reduced tillage in sorghum-mung bean strip cropping system in terms of sustainability of crop yields and long term effects on soil quality in Alfisol

Objective 3: To study the response of sorghum-cowpea system to graded level of surface residue application under minimum tillage in Alfisol and effects on carbon storage.

Objective 4: To study the influence of conjunctive use of residues and graded levels of N on crop yields and predominant N pools under sorghum-castor system.

- In order to achieve these objectives, soil quality assessment as influenced by different soil and nutrient management practices (Tillage, residue, INM treatments etc.) across rainfed agro ecology was under taken. In all, seven centers viz. Parbhani (Maharashtra), Dantiwada (Gujarat), Agra (Uttar Pradesh), Hissar (Haryana), Hoshiarpur (Punjab), Arjia (Rajasthan), Rakhdhiansar (Jammu & Kashmir) of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) falling in different states and some of the on-going long term experiments on conservation agriculture and soil quality improvement were adopted for the study under National Fellowship Program. In addition to that , during the period of study, soil quality assessment was also under taken in an another on-going AP Cess fund program for other seven centres viz. Phulbani, (Orissa), Ranchi (Jharkhand), Anantapur (Andhra Pradesh), Rajkot (Gujarat), Akola (Maharashtra), Kovilpatti (Tamilnadu) and Indore (Madhya Pradesh). For these centres also, predominant long term soil and nutrient management treatments were evaluated for their potential to aggrade / improve soil quality, key indicators were identified for different cropping systems under different soil types. Soil quality indices (SQI) were also calculated to screen the best soil and nutrient management.

- Besides, the studies undertaken for Centres, the three field experiment were also conducted at Hyderabad centre in Alfisol on soil quality restoration, assessment and improvement.
- Data set was generated for 21 soil quality variables (Physical, Chemical and Biological) through rigorous soil analysis.
- Key indicators of soil quality were identified for varying cropping system under different soils for all the eight locations using the 'State of the Art' methodology being followed at international level. The key steps of the methodology were comprised of the following:
    - Complete laboratory analysis for predominant soil quality variables
    - Testing the level of significance for various soil indicator as influenced by various management treatments
    - Fixing or defining the goals
    - Selecting representative minimum data set (MDS) through Principal component analysis (PCA)
    - Correlation analysis among soil variables to reduce spurious grouping among highly weighted variables within each PC
    - Multiple regressions using the final MDS components as the independent variables and each goal attribute as a dependent variables
    - Scoring of the MDS indicators based on their performance of soil function and
    - Computation of soil quality indices (SQI)
- **Annual reports along with (Statement of Expenditure) SOE were submitted to ADG (HRD), ICAR for all the years viz. 2005-06, 2006-07, 2007-08, 2008-09 for National Fellow Project.** Similarly, reports pertaining to AP Cess Fund Program were submitted to ADG (Agronomy), NRM, ICAR for the years (2005-06, 2006-07, and 2007-08 along with a consolidated report (2005-08).

The salient findings of the study were as follows:

Objective 1: To evaluate the long term influence of existing selected soil and nutrient management practices on soil quality parameters, to identify the key indicators and to compute the soil quality indices under different cropping systems in rainfed areas across the country.

Phulbhani Centre

Experiment 1: Organic farming comprising of INM treatments and legume based cropping systems

The four cropping systems adopted were: i) Sorghum + pigeon pea (4:2), ii) Soybean + pigeon pea (4:2), iii) Cotton + black gram (1:1) and iv) Mung bean + rabi sorghum.

a) Sorghum + pigeon pea (4:2) system

- The key soil quality indicators for sorghum + pigeon pea system were found to be organic carbon, available S, dehydrogenase assay, labile carbon and mean weight diameter.
- The soil quality indices varied from 1.68 to 2.47, while the relative soil quality indices (RSQI) varied from 0.66 to 0.97 across the INM treatments.
- Among all the INM treatments, significantly highest soil quality index was observed with application of FYM@ 5 t ha^{-1} (2.47) which was at par with 25% RDF + FYM@ 2.5 t ha^{-1} (2.43). It was observed that the treatments which received FYM had the highest soil quality which was followed by the treatments which received gliricidia biomass as nutrient component.
- Irrespective of their statistical significance, the relative order of performance of treatments in terms of influencing soil quality were: F1: FYM@ 5 t ha^{-1} (2.47) > F4: 25% RDF + FYM@ 2.5 t ha^{-1} (2.43) > F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1} (2.31) > F2: Gliricidia @ 3 t ha^{-1} (semi dried) (2.30) > F3: RDF (2.27) > Control with rotation (1.75) > Absolute control without rotation (1.68).
- The percent contributions of key indicators towards soil quality indices were: Mean weight diameter (29%), labile carbon (28%), dehydrogenase assay (26%), organic carbon (10%) and available S (7%).

ii) Soybean + pigeon pea (4:2) system

- The key indicators for soybean + pigeon pea (4:2) system in Vertisol at Parbhani included pH, available S, dehydrogenase assay, labile carbon and mean weight diameter.
- Soil quality indices varied from 1.48 to 2.16 while the RSQI values varied from 0.68 to 0.99 across the INM treatments.

- The treatment which received FYM@ 5 t ha^{-1} maintained significantly highest soil quality index of 2.16 followed by the application of Gliricidia @ 3 t ha^{-1} (semi dried) (2.00).
- Irrespective of their statistical significance, the relative order of performance of treatments in terms of influencing soil quality was: F1: FYM@ 5 t ha^{-1} (2.16) > F2: Gliricidia @ 3 t ha^{-1} (semi dried) (2.00) > F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1} (1.97) > F4: 25% RDF + FYM@ 2.5 t ha^{-1} (1.90) > F3: RDF (1.79) Control with rotation (1.60) > Absolute control without rotation (1.48).
- The percent contributions of key indicators towards soil quality indices were: pH (7%), available S (8%), dehydrogenase assay (29%), labile carbon (31%) and mean weight diameter (25%).

iii) Cotton + black gram (1:1) system

- The key indicators for Cotton + Blackgram (1:1) system in Vertisol at Parbhani included pH, organic carbon, available K, available S, available Mn, dehydrogenase assay, labile carbon and mean weight diameter
- The soil quality indices varied from 2.07 to 2.49 while the RSQI values varied from 0.78 to 0.96 across the INM treatments.
- Significantly highest soil quality indices were observed with application of 25% RDF + FYM@ 2.5 t ha^{-1} (2.54) as well as Gliricidia @ 3 t ha^{-1} (semi dried) (2.51) which was at par with other treatments also.
- The relative order of performance of treatments in terms of influencing soil quality, irrespective of their statistical significance was: F4: 25% RDF + FYM@ 2.5 t ha^{-1} (2.54) > F2: Gliricidia @ 3 t ha^{-1} (semi dried) (2.51) > F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1} (2.49) > F3: RDF (2.43) F1: FYM@ 5 t ha^{-1} (2.48) > Control with rotation (2.15) > Absolute control without rotation (2.07).
- The percent contributions of key indicators towards soil quality indices were: pH (5%), organic carbon (21%), available K (4%), available S (5%), available Mn (21%), dehydrogenase assay (19%), labile carbon (20%) and mean weight diameter (5%).

iv) Mung bean + rabi sorghum system

- The key indicators for mung bean + rabi sorghum system in Vertisol at Parbhani were: available K, available S, available Mn, microbial biomass carbon as well as labile carbon.
- The soil quality indices varied from 2.00 to 2.70 while the RSQI values varied from 0.66 to 0.99 across the INM treatments.
- The treatments, which received FYM, showed the highest soil quality followed by the treatments, which received gliricidia biomass loppings.

- The order of performance and superiority of treatments in terms of influencing soil quality was : F1: FYM@ 5 t ha^{-1} (2.70) > F4: 25% RDF + FYM@ 2.5 t ha^{-1} (2.55) = F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1} (2.55) > F2: Gliricidia @ 3 t ha^{-1} (semi dried) (2.47) > F3: RDF (2.36) > Control with rotation (2.08) > Absolute control without rotation (2.00).
- The percent contributions of key indicators towards soil quality indices were: available K (23%), available S (9%), available Mn (23%), microbial biomass carbon (21%) as well as labile carbon (24%).

Dantiwada Centre

Experiment 1: Long-term manurial trial under pearl millet system

- The key indicators for pearl millet system under Aridisols of Dantiwada were organic carbon, available N, exchangeable Ca and Mg, available Zn, labile carbon and bulk density.
- The soil quality indices varied from 1.77 to 2.46 and RSQI values when reduced to a scale of one varied from 0.71 to 0.99 across the long-term manurial treatments.
- , The relative order of performance and superiority of the treatments in influencing soil quality Index was: T5: 50 % RDN (urea) + 50% RDN (FYM) (2.46) > T4: 50 % RDN through FYM (2.37) > T6: Farmers method 5 t FYM ha^{-1} once in three years (2.31) > T2: 100 % RDN through urea (2.23) > T3: 50 % RDN through urea (2.00) > T1: Control (1.77).
- The average percent contribution of key indicators towards soil quality indices was: organic carbon (19.9%), available N (11.3%), exchangeable Ca (7.1%) and Mg (20.8%), available Zn (10.9%), labile carbon (17.7%) and bulk density (12.2%).

Agra Centre

Experiment 1: Long-term experiment in major production system

- The key soil quality indicators for pearl millet system under Entisols of Agra were: organic carbon, available N, exchangeable Ca, Available Zn and Cu, labile carbon and mean weight diameter.
- The soil quality indices varied from 2.33 to 3.47 while the RSQI values varied from 0.64 to 0.95 across the long-term integrated nutrient management treatments practiced for pearl millet system
- Among all the manurial treatments practiced, the application of 50% urea + 50% FYM showed the highest soil quality index of 3.47 which was at par with 100% RDF + 25 kg $ZnSO_4$ (3.20).

- Irrespective of their statistical significance, the relative order of performance of the INM treatments in influencing soil quality in terms of SQI was: T3: 50% urea + 50% FYM (3.47) > T4: 100% RDF + 25 kg $ZnSO_4$ (3.20) > T2: 50% urea + 50% Crop residue (3.01) > T5: Farmers method (2.77) > T1: Control (2.33).
- The quantum of percent contribution of key indicators towards soil quality indices was: organic carbon (19%), available N (20%), exchangeable Ca (3%), Available Zn (4%) and Cu (17%), labile carbon (20%) and mean weight diameter (17%).

Experiment 2: Tillage and nutrient management for resource conservation and improving soil quality

- The key soil quality indicators for pearl millet system under Entisols of Agra were: organic carbon, exchangeable Ca, available Zn, available Cu, dehydrogenase assay, microbial biomass carbon and mean weight diameter.
- The soil quality indices varied from 0.86 to 1.08 while the RSQI values varied from 0.72 to 0.90 across the tillage and nutrient management treatments practiced for pearl millet system
- Tillage as well as the nutrient management treatments played a significant role in influencing the soil quality indices while their interaction effects were not so conspicuous on soil quality indices.
- Among the tillage treatments, practice of low tillage with one interculture + weedicide application resulted in higher soil quality index of 0.98 followed by practice of conventional tillage + one interculture (0.94) which was at par with the practice of low tillage + one interculture (0.93).
- Among the nutrient management treatments, application of nutrients through 100% organic sources maintained highest soil quality with SQI value of 1.05 while the other two nutrient management practices viz., 50% N (organic) + 50 % (inorganic source) as well as 100% N (inorganic source) with SQI values of 0.92 and 0.88 respectively, maintained soil quality at par with each other.
- Irrespective of their statistical significance, the relative order of performance in influencing soil quality in terms of SQI was: CT + IC + 100% N (organic source/compost) (1.08) > LT + Weedicide + IC + 100% N (organic source/compost) (1.05) > LT + IC + 100% N (organic source/compost) (1.02) > LT + Weedicide + IC + 50% N (organic) + 50 % inorganic source) (0.99) > LT + Weedicide + IC + 100% N (inorganic source) (0.90) > LT + IC + 100% N (inorganic source) (0.89) > CT + IC + 50% N (organic) + 50 % inorganic source) (0.88) = LT + IC + 50% N (organic) + 50 % inorganic source) (0.88) > CT + IC + 100% N (inorganic source) (0.86).

- The various key indicators which contributed towards soil quality indices were: organic carbon (17%), exchangeable Ca (10%), available Zn (9%), available Cu (6%), dehydrogenase assay (6%), microbial biomass carbon (25%) and mean weight diameter (27%).

Experiment 3: Farmers fields

- Three cropping systems selected under farmer's fields at Agra were evaluated for their performance in maintaining soil quality
- On the whole, it was observed that, except for available P, K, labile carbon and bulk density, the influence of cropping systems was not conspicuous on any of the soil quality parameters chosen under this study.
- The soils were neutral to slightly alkaline in reaction with pH varying from 7.05 to 7.68 and electrical conductivity ranging from 0.25 to 0.32 dSm^{-1}. Organic carbon as well as available N under these cropping systems was low ranging from 4.20 to 4.56 g kg^{-1} and 130.6 to 141.8 kg ha^{-1} respectively. On the other hand, available P was medium to high varying from 22.6 to 43.7 kg ha^{-1} while available K was medium varying from 183.2 to 271.1 kg ha^{-1} across the cropping systems. The status of available S as well as the micronutrient contents was satisfactory in these soils.
- Among the biological soil quality parameters, dehydrogenase activity was quite good ranging from 7.21 to 9.04 μg TPF $hr^{-1}g^{-1}$ across the cropping systems, while the microbial biomass carbon values were recorded to be low as the analysis was carried out in relatively dry soil samples. On the other hand, labile carbon was significantly higher under pigeonpea + green gram system (263.1 μg g^{-1} of soil) followed by green gram and mustard system (235.6 μg g^{-1} of soil) while the lowest was recorded under pearl millet + cluster bean system (226.8 μg g^{-1} of soil).
- Contrarily, bulk density was lowest under pearl millet + cluster bean system (1.29 Mg m^{-3}) and was highest under green gram + mustard system (1.39 Mg m^{-3}).
- In this experiment, the influence of various cropping systems on soil quality parameters was found to be non-significant except available P, K, labile carbon and bulk density. Hence, soil quality indices could not be computed for these farmers' fields at this centre

Hissar Centre

Experiment 1: Integrated nutrient supply for rainfed semiarid tropics under pearl millet and mungbean system

- The key indicators for pearl millet -mung bean system included pH, available N, K, Zn, Cu and dehydrogenase activity . The soil quality indices varied from 1.11 to 1.52 and the

RSQI values varied from 0.70 and 0.97 across the management treatments practiced for pearl millet and mung bean system.

- Application of 25 kg N through compost showed the highest soil quality index of 1.52 and its performance was observed to be almost at par with all the other treatments except control.
- Irrespective of their statistical significance, the relative order of performance in influencing soil quality in terms of SQI was: T3: 25 kg N (compost) (1.52) > T6: 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer (1.49) > T5: 15 kg N (compost) + 10 kg N (GLM) (1.47) > T4: 15 kg N (GLM) + 20 kg N (inorganic) (1.46) > T2: 100 % N (inorganic) (1.45) and T1: Control (1.11**).**
- The magnitude and extent of contribution of key indicators towards soil quality indices was: available N (35%), available Zn (35%), available Cu (10%), pH (10%), available K (5%) and dehydrogenase assay (5%).

Experiment 2: Organic farming studies on rainfed mustard

- The key soil quality indicators identified for mustard system in Aridisols of Hissar included available P, exchangeable Mg, and available Zn & Fe.
- The soil quality indices varied from 0.71 to 1.04 and the RSQI values varied between 0.65 and 0.95 across the manurial treatments practiced for mustard system
- Among all the manurial treatments practiced, the application of FYM @ 4 t ha^{-1} showed the highest soil quality index of 1.04 and its performance was observed to be almost at par with all the treatments.
- , The relative order of performance in influencing soil quality in terms of SQI was: T2: FYM (4 t ha^{-1}) (1.04) > T5: Cowpea green manure (40 DAS) (1.00) > T3: Vermiculture (4 tha^{-1}) (0.95) > T4: Diancha Green manure (40 DAS) (0.89) > T1: Control (0.71).
- The average percent contribution of key indicators towards soil quality indices was: available Zn (63%), exchangeable Mg (13%), available Fe (11%) and available P (7%).

Experiment 3: Tillage and nutrient management strategies for resource conservation and improving soil quality and productivity of rainfed pearl millet

- The key indicators for rainfed pearl millet system in Aridisols at Hissar included EC, available N, exchangeable Mg, available Mn, DHA, MBC and BD. The soil quality indices varied from 1.50 to 1.74 while the RSQI values varied between 0.83 and 0.96 across the tillage and nutrient management treatments practiced for rainfed pearl millet system
- The practice of conventional tillage (CT) + two intercultures (IC) + 100% N (organic source/compost) and CT + two IC + 100% N (inorganic source) maintained the highest

soil quality indices of 1.74 which was at par with other tillage and nutrient management practices.

- When averaged over the nutrient management treatments, practice of conventional tillage with two interculture operations performed better in maintaining significantly highest soil quality index of 1.74, while the practice of low tillage with two interculture operations or weedicide application + one interculture operation, both maintained the soil quality index of 1.60.
- The application of 100% N through organic sources recorded significantly highest SQI of 1.69 which was at par with the other treatments.
- Irrespective of their statistical significance, the relative order of performance in influencing soil quality in terms of SQI was: T1: CT + Two IC + 100% N (organic source/compost) (1.74) > T3: CT + Two IC + 100% N (inorganic source) (1.74) > T4: LT + Two IC + 100% N (organic source/compost) (1.70) > T8: LT + Weedicide + One IC + 50% N (organic) + 50 % inorganic source) (1.68) > T2: CT + Two IC + 50% N (organic) + 50 % inorganic source) (1.64) > T7: LT + Weedicide + One IC + 100% N (organic source/compost) (1.63) > T5: LT + Two IC + 50% N (organic) + 50 % inorganic source) (1.59) > T6: LT + IC + 100% N (inorganic source) (1.50) > T9: LT + Weedicide + One IC + 100% N (inorganic source) (1.50).
- The average percent contribution of key indicators towards soil quality indices was: EC (15%), available N (19%), exchangeable Mg (18%), available Mn (13%), dehydrogenase assay (19%), microbial biomass carbon (5%) and bulk density (11%).

Experiment 4: Cropping systems at Farmers fields

- The key soil quality indicators for different cropping systems practiced in farmers fields of Hissar included pH, available K, exchangeable Ca & Mg, available Cu, labile carbon and bulk density.
- The soil quality indices varied from 2.87 to 4.13 while the RSQI values varied between 0.65 and 0.93 across the farmer's fields.
- The undisturbed system had the highest SQI of 4.13. But among the cropping systems, the mung bean system had the highest SQI of 3.82.
- Irrespective of their statistical significance, the relative order of performance of the cropping systems in influencing soil quality in terms of SQI was: Undisturbed (4.13) > Mung bean (3.82) > Pearl millet- Fallow (3.00) > Fallow – Chickpea (2.87).
- The average percent contribution of key indicators towards soil quality indices was: pH (22%), available K (16%), exchangeable Ca (14%), exchangeable Mg (4%), available Cu (9%), labile carbon (15%) and bulk density (20%).

Hoshiarpur Centre

Experiment 1: Integrated nutrient management practices in maize/black gram – wheat/lentil cropping systems under rainfed semi-arid tropics

- The key indicators for different soil- nutrient management (INM) treatments under Maize-Wheat based cropping sequence in Inceptisols of Ballowal Saunkhri included available N, available P, available K, exchangeable Ca and microbial biomass carbon.
- The soil quality indices varied from 1.16 to 1.61 while the RSQI values varied from 0.70 to 0.98 across the treatments.
- Application of 25 kg N (compost) (1.61) as well as application of 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) both recorded the highest SQI of 1.61.
- Irrespective of their statistical significance, the relative order of performance of the nutrient management treatments in influencing soil quality in terms of SQI was: T4: 25 kg N (compost) (1.61) = T9: 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) (1.61) > T2: 100% RDN (80 kg N ha^{-1}) (1.48) > T6: 15 kg N (compost) + 20 kg N ha^{-1} (inorganic) (1.47) > T7: 15 kg N (green leaf) + 10 kg N ha^{-1} (inorganic) (1.46) > T5: 15 kg N (compost) + 10 kg N ha^{-1} (inorganic) (1.45) > T3: 50% RDN (80 kg N ha^{-1}) (1.41) > T8: 15 kg N (green leaf) + 20 kg N ha^{-1} (inorganic) (1.32) > T1: No Fertilizer (1.16).
- The average percent contribution of key indicators towards soil quality indices was: available N (13%), available P (32%), available K (34%), exchangeable Ca (9%) and microbial biomass carbon (12%).

Experiment 2: Effect of tillage and sources of nitrogen on the crop productivity in maize-wheat cropping sequence under dryland conditions

- The key soil quality indicators for different tillage and soil-nutrient management treatments under maize-wheat cropping sequence in Inceptisols of Ballowal Saunkhri, Hoshiarpur included viz., pH, electrical conductivity, organic carbon, available N, available P, exchangeable Mg and available S.
- In this experiment, the soil quality indices varied from 0.96 to 1.19 while the RSQI values varied between 0.80 and 0.99 across the tillage and nutrient management treatments.
- Tillage, nutrient management treatments as well as their interaction effects had significant influence on soil quality indices. Among the tillage treatments, practice of conventional tillage + one interculture maintained significantly highest soil quality with SQI of 1.12 which was almost at par with practice of 50% CT + one interculture + chemical weed control (1.08).

- Among the nutrient management treatments, application of nutrients through 50% N (organic) + 50 % (inorganic) source maintained higher soil quality with SQI of 1.10 followed by application of 100% organics (1.08).
- Of all the treatments, 50 % CT + IC + CWC + 50% N (organic) + 50 % (inorganic) source maintained highest soil quality with SQI of 1.19 which was at par with CT + IC + 100% N (organic source/compost) (1.16).
- The average contribution of key indicators towards soil quality indices was: pH (12%), electrical conductivity (6%), organic carbon (31%), available N (14%), available P (14%), exchangeable Mg (13%) and available S (10%).

Experiment 3: Farmer's fields

- The key soil quality indicators for different cropping systems practiced in farmer's fields in Inceptisols of Ballowal Saunkhri, Hoshiarpur included available N, available P, available K, exchangeable Mg, available S, Available Zn, available Mn and available B. It was surprised to observe that this MDS did not include any of the biological or physical soil quality indicators.
- The soil quality indices varied from 1.11 to 1.61 while the RSQI values varied from 0.67 to 0.98 across the farmer's fields. Maize-wheat system maintained the highest soil quality with SQI value of 1.61 followed by agroforestry (dhek) system (1.35).
- Irrespective of their statistical significance, the relative order of performance of the cropping systems in influencing soil quality in terms of SQI was: Maize- Wheat (1.61) > Agroforestry (Dhek) - Gnut/ Wheat/ Lentil/ Taramira (1.35) > Agri-Horti (Guava)- Gnut/ Barley/ Wheat / Lentil-Guava) (1.29) > Agri-Horti (Peach)- Gnut/Barley/Wheat /Taramira) (1.24) > Agroforestry (Dhek)- Gnut/ Blackgram/ Bajra (F) (1.16) > Pearlmillet-Oilseed (1.11).
- The average percent contribution of key indicators towards soil quality indices was: available N (11%), available P (4%), available K (22%), exchangeable Mg (7%), available S (12%), Available Zn (8%), available Mn (10%) and available B (26%). Of all these indicators, available B contributed more to SQI followed by available K in these soils.

Arjia Centre

Experiment 1: Low till farming strategies for resources conservation and improving soil quality

- The key soil quality indicators for different tillage and soil-nutrient management treatments under Maize-Blackgram system in Inceptisols of Arjia included soil pH, organic carbon, available N, available Zn, available Fe, and labile carbon.

- The soil quality indices varied from 1.62 to 1.89 while the RSQI values varied from 0.84 to 0.98 across the tillage and nutrient management treatments.
- Tillage showed a significant influence while the nutrient management treatments did not show any significant influence in maintaining soil quality while their interaction effects had a significant influence.
- Among the tillage methods, practice of low tillage + herbicide + 1 weedicide + hoeing maintained significantly highest SQI of 1.84 followed by the other two methods.
- Of all the treatments, practice of LT + herbicide + 1 weedicide + hoeing + 100% inorganic N maintained significantly highest SQI of 1.89 which was at par with LT + herbicide + 1 weedicide + hoeing + 100% organic N (1.87).
- The average percent contribution of key indicators towards soil quality indices was: soil pH (8%), organic carbon (24%), available N (16%), available Zn (8%), available Fe (16%), and labile carbon (28%).

Experiment 2: Integrated nutrient supply system for rainfed semiarid tropics under maize, blackgram strip and block system

- Soils of the experimental field were found to be almost neutral in reaction tending towards salinity with pH of 7.25 to 7.32. Electrical conductivity of the soils ranged from 0.18 to 0.22 dS m^{-1} and organic carbon 3.9 to 4.7 g kg^{-1}.
- It was clearly observed that the macronutrient content i.e., available N, P and K content of the soils were not significantly influenced by the type of cropping systems. However, available nitrogen in these systems ranged from 123.2 to 127.8 kg ha^{-1}, available phosphorus form 19.2 to 33.8 kg ha^{-1} and available potassium from 321.4 to 364.3 kg ha^{-1}.
- Exchangeable calcium in the soils was significantly influenced by the cropping systems and ranged from 7.8 to 16.8 cmol kg^{-1}. Among the systems, strip system of maize and black gram recorded the highest exchangeable calcium (16.8 kg cmol kg^{-1}) while blocks of black gram recorded the lowest (7.8 kg ha^{-1}). Exchangeable magnesium was also not significantly influenced by the management treatments. Available sulphur in these soils was significantly influenced by the cropping system and was found to be highest under strip system of maize-blackgram (10.88 kg ha^{-1}), while it was lowest under black gram block system (7.92 kg ha^{-1}).
- The cropping systems did not show any significant influence on the DTPA extractable micronutrients except Mn. However, Zn, Fe, Cu and B in these soils ranged from 1.59 to 1.78, 6.68 to 7.76, 2.6 to 3.5 and 0.72 to 0.80 µg g^{-1} of soil respectively. Strip system of maize-blackgram recorded significantly highest available Mn (13.65 µg g^{-1} of soil) while, blocks system of black gram recorded the lowest amount (6.59 µg g^{-1} of soil).

- There was no significant influence of crop blocks under maize-blackgram system on physical and biological soil quality parameters. However, dehydrogenase activity in the soil ranged from 1.19 to 2.09 μg TPF $hr^{-1}g^{-1}$, microbial biomass carbon from 108.4 to 115.7 μg g^{-1} of soil and labile carbon 291.0 to 303.8 μg g^{-1} of soil. The bulk density in the systems varied from 1.26 to 1.32 Mg m^{-3} while the mean weight diameter varied from 0.13 to 0.19 mm.
- As most of the soil quality parameters were not significantly influenced by the management treatments, soil quality assessment using principal component analysis was not done and soil quality indices could not be computed.

Experiment 3: Soil quality assessment under Farmers fields

- The key indicators for different cropping systems under farmers fields Inceptisols of Arjia included six soil quality variables viz., organic carbon, exchangeable Ca, available Fe, dehydrogenase assay, labile carbon and bulk density.
- The soil quality indices varied from 2.77 to 3.53 while the RSQI values varied from 0.76 to 0.98 across the various cropping systems under farmers fields.
- Among the cropping systems, groundnut-sesame system maintained highest soil quality index (3.53) and was at par with maize-blackgram system (3.38) while groundnut-taramira system maintained the lowest SQI of 2.77.
- The relative order of performance of management treatments in influencing soil quality indices, was: Groundnut- Sesame (3.532) > Maize-Blackgram (3.375) > Groundnut-Taramira (2.765).
- The average percent contribution of key indicators towards soil quality indices was: organic carbon (20%), exchangeable Ca (18%), available Fe 92%), dehydrogenase assay (14%), labile carbon (23%) and bulk density (23%).

Rakhdhiansar Centre

Experiment 1: Integrated nutrient supply system for rainfed semi-arid tropics

- The six key soil quality indicators for maize-black gram system practiced in Inceptisols of Rakhdhiansar included exchangeable Ca, available N, available Zn, & B, microbial biomass carbon and bulk density.
- Soil quality indices varied from 2.68 to 4.17 while the RSQI varied from 0.63 to 0.97 across the integrated nutrient management treatments.
- Application of 25 kg N compost had significantly highest RSQI of 0.97 which was at par with application of 15 kg N (compost) + 20 kg N (inorganic) (0.94).

- Irrespective of their statistical significance, the relative order of performance of the treatments in influencing the soil quality indices were: T4: 25 kg N (compost) (4.17) > T6: 15 kg N (compost) + 20 kg N (inorganic) (4.05) > T5: 15 kg N (compost) + 10 kg N (inorganic) (3.75) > T2: 100 % N (inorganic) (3.55) > T3: 50 % N (inorganic) (3.46) > T1: Control (2.68).
- The contribution of key indicators towards soil quality was: available N (3.49%), exchangeable Ca (19.6%), available Zn (16.6%), available B (19.3%), microbial biomass carbon (19.7%), bulk density (21.4%).

Experiment 2: Permanent manurial trial in maize crop

- The key soil quality indicators identified for maize system in Inceptisols of Rakhdhiansar were: pH, EC, organic carbon, available P, available S, available Zn, dehydrogenase assay and microbial biomass carbon.
- The manurial treatments had significant influence on soil quality indices, which varied from 0.97 to 1.52 across the management treatments, while the relative soil quality indices varied from 0.62 to 0.98.
- Of the different manurial treatments applied to maize crop, application of 50%N (FYM) as well as application of 50% NPK + 50% N (FYM) performed equally well in maintaining the soil quality with a SQI value of 1.52 and these were at par with 50% NPK + 50% N (Crop residue) (1.46). However, the control plot recorded the lowest RSQI of 0.97.
- Irrespective of their statistical significance, the relative order of performance of the manurial treatments in terms of influencing soil quality indices were: T5: 50%N (FYM) (1.52) > T7: 50% NPK + 50% N (FYM) (1.52) > T6: 50% NPK + 50% N (Crop residue) (1.46) > T2: 100% NPK (60:40:20 kg ha^{-1}) (1.38) > T3: 50% NPK (1.33) > T4: 50%N (crop residue) (1.25) > T1: Control (0.97).
- The percent contribution of key indicators towards soil quality indices was computed and it was observed that among all the key indicators, available S and microbial biomass carbon contributed a maximum percentage of 31.9 and 31.8% respectively while the other indicators which contributed relatively less were: pH (8.05%), EC (6.01%), organic carbon (4.87%), available P (4.45%), available Zn (4.56%) and dehydrogenase assay (8.36%).

Experiment 3: Nutrient management in maize- wheat rotation

- The key soil quality indicators under maize-wheat rotation included organic carbon, available N, available P, available K, available Fe & Zn, microbial biomass carbon, bulk density and mean weight diameter.

- The nutrient management treatments significantly influenced the soil quality indices which varied between 3.69 to 5.66 across the management treatments while the relative soil quality indices varied between 0.63 to 0.96.
- Of all the nutrient management treatments, application of FYM @ 10 t ha^{-1} + 40 kg N ha^{-1} maintained significantly highest SQI of 5.66 which was at par with application of FYM @ 10 t ha^{-1} + 30 kg N ha^{-1} and green manuring with Sunhemp + 20 kg N ha^{-1} both of which maintained SQI of 5.40.
- Irrespective of their statistical significance, the relative order of performance of the nutrient management treatments in maintaining the soil quality indices were: T4: FYM @ 10 t ha^{-1} + 40 kg N ha^{-1} (5.66) > T5: Green manuring with Sunhemp + 20 kg N ha^{-1} (5.44) > T3: FYM @ 10 t ha^{-1} + 30 kg N ha^{-1} (5.40) = > T2: FYM @ 10 t ha^{-1} + 20 kg N ha^{-1} (5.16) > T1: Control (3.69).
- The percent contributions of each of these key indicators towards soil quality indices were also computed. It was observed that almost all the key indicators contributed more or less equally towards the soil quality indices except available N and available Fe, which contributed to a minimum extent of 2.27 % and 1.90% respectively. The percent contribution of the other key indicators was as follows: organic carbon (13.8%), available P (13.4%), available K (14.5%), available Zn (12.6%), microbial biomass carbon (13.7%), bulk density (16.2%) and mean weight diameter (11.6%).

Experiment 4: Tillage and nutrient management for resource conservation and improving soil quality.

- The key soil quality indicators for maize cropping system in Inceptisols of Rakhdhiansar included available P, available S, available Zn & B, labile carbon and mean weight diameter.
- Tillage treatments did not show any significant influence in improving the soil quality while the nutrient management treatments played a significant role in maintaining the soil quality. The soil quality indices varied between 1.28 to 1.58 while the relative soil quality indices varied between 0.79 to 0.97 across the management treatments.
- Among the nutrient management treatments, application of 100% N through organic sources maintained significantly highest soil quality (1.52) followed by application of 50% N through organic sources + 50 % N through inorganic sources (1.36) which was at par with the application of 100% N through inorganic sources (1.33).
- The percent contribution of these key indicators towards soil quality indices was as follows: available P (11.0%), available S (7.23%), available Zn (8.99%), available B (23.3%), labile carbon (26.6%) and mean weight diameter (22.9%).

Experiment 5: Farmers Fields

- The cropping systems practiced in farmer's fields when statistically tested for their influence on soil quality parameters proved insignificant for almost all the parameters except for dehydrogenase activity as well as microbial biomass carbon.
- However, soils under these cropping systems were near neutral to neutral in reaction with EC ranging from 0.18 to 0.21 dS m^{-1}. Organic carbon was observed to be low in these cropping systems varying from 3.90 to 4.11 g kg^{-1}. Among the macronutrients, available N was very low in these soils (142.2 to 167.2 kg ha^{-1}) while available P and K were high and medium with values ranging from 24.8 to 35.2 kg ha^{-1} and 249.0 to 283 kg ha^{-1} respectively across the cropping systems.
- Exchangeable Ca and Mg were found to be adequate ranging from 3.68 to 4.69 cmol kg^{-1} and 0.69 to 0.98 cmol kg-1 respectively across the various cropping systems. Available S was medium to high in these soils ranging from 14.3 to 18.0 kg ha^{-1}. Among the micronutrients, all the micronutrients viz., Zn, Fe Mn and B were observed to be high in these soils ranging from 1.17 to 1.34, 9.50 to 11.7, 12.5 to 14.7 and 0.73 to 0.88 μg g^{-1} respectively while Cu was medium (0.53 to 0.67 μg g^{-1}) across the different cropping systems under farmers fields.
- Among the biological soil quality parameters, dehydrogenase activity as well as microbial biomass carbon was significantly influenced by the cropping systems practiced while labile carbon content was not conspicuously influenced. Dehydrogenase activity varied from 2.75 to 4.69 μg TPF $hr^{-1}g^{-1}$ across the cropping systems and significantly highest DHA was recorded under blackgram- wheat system (4.69 μg TPF $hr^{-1}g^{-1}$) followed by Maize-Wheat system (3.94 μg TPF $hr^{-1}g^{-1}$) while maize-toria-wheat system recorded the lowest (2.75 μg TPF $hr^{-1}g^{-1}$). Microbial biomass carbon was significantly highest under pearl millet-wheat system (206.6 μg g^{-1} of soil), which was at par with maize-toria-wheat system (199.9 μg g^{-1} of soil). Labile carbon varied between 323.7 to 360.7 μg g^{-1} of soil across the cropping systems and was not significantly influenced.
- Bulk density under these cropping systems ranged from 1.40 to 1.45 Mg m^{-3} while the mean weight diameter varied from 0.22 to 0.29 mm and were not influenced by the cropping systems.
- As majority of the soil quality indicators studied in farmer's fields were not significantly influenced by the cropping systems, soil quality indices could not be computed.

Assessment of chemical soil quality in rainfed farmers fields of Ranga Reddy district of Andhra Pradesh

- Study was initiated with the objective to assess soil quality in rainfed farmer's fields and develop soil chemical quality index in collaboration with Krishi Vigyan Kendra (KVK) of this Institute under Frontline Demonstration experiments on Maize. Soil samples collected by KVK centre from 338 rainfed farmer's fields representing two mandals (Shabad and Kandukur) covering 8 villages (Bobbligum, Pulimamidi, Moddemguda, Pochammathanda, Pulimamidi, Saireddyguda, Saralaraopalli and Thandamucherla) of Rangareddy district predominantly representing two soil types (Black and red) were analyzed for 13 soil chemical health indicators (pH, EC, OC, available N, P, K, exchangeable Ca, Mg, DTPA extractable Zn, Fe, Cu, Mn and DTPA-sorbitol extractable boron).
- The results were processed and a computer generated soil chemical health test reports with specific indications and suggestions were prepared with the help of other associated Scientist and programmer of the institute and issued to KVK section for distribution to the farmers. A sample of computer generated soil chemical health report is appended.

Objective 2: To evaluate the low-cost integrated nutrient management (INM) treatments (comprising of farm based organics) under conventional and reduced tillage in sorghum-mung bean strip cropping system in terms of sustainability of crop yields and long term effects on soil quality in Alfisol

- ❖ An on going experiment which was started during 1998 was adopted for the study. During the period of this report also field experiment were conducted. Pooled analysis of grain yield data of sorghum as influenced by tillage and INM treatments was done for a period of ten years.

Sorghum grain yields

- ❖ Over ten years of experimentation, the nutrient management treatments showed a significant influence on sorghum grain yields. Out of these ten years period, significantly highest sorghum grain yields were observed during the year 2002 (1929 kg ha^{-1}) followed by the year 2004 (1682 kg ha^{-1}) while the lowest yields were observed during the year 2005 (1165.3 kg ha^{-1}).
- ❖ On an average, over the years, conventional tillage performed significantly well in maintaining higher sorghum grain yield (1592.7 kg ha^{-1}) which was 14% higher compared to the minimum tillage practice (1397.2 kg ha^{-1}).
- ❖ Among the nutrient management treatments, when averaged over years as well as tillage, , application of 2 t Gliricidia loppings + 20 kg N through urea to sorghum crop recorded

significantly highest sorghum grain yield of 1706.3 kg ha^{-1} followed by both application of 4 t compost + 20 kg N through urea (1664.9 kg ha^{-1}) as well as 40 kg N through urea (1648.5 kg ha^{-1}) and were at par with each other.

- When compared to control, the percent increase in sorghum grain yields under all the nutrient management treatments were: T4 =2 t Gliricidia loppings + 20 kg N through urea (98.8%) > T3 = 4 t compost + 20 kg N through urea (94.0%) = T2 = 40 kg N through urea (92.1%) > T5 = 4 t compost + 2 t gliricidia loppings (86.1%).

Mungbean grain yields

- As in case of sorghum, pooled analysis of grain yield data of mungbean as influenced by tillage and INM treatments was also done for a period of ten years.
- Over a period of ten years, tillage as well as the nutrient management treatments played a significant influence on mungbean grain yields. Out of the ten years of experimentation, mung bean grain yields were highest (1204 kg ha^{-1}) during the year 2004 followed by the yields during the year 2007 (1030 kg ha^{-1}) while the lowest grain yields were recorded during the year 2000 (459.4 kg ha^{-1}).
- Of the two tillage methods, when averaged over the nutrient management treatments for a period of ten years, conventional tillage showed significantly higher mung bean grain yields (876.5 kg ha^{-1}) compared to minimum tillage (814 kg ha^{-1}).
- The percent increase in mungbean grain yields under conventional tillage was to the extent of 8% over minimum tillage. Among the nutrient management treatments, when averaged over the tillage, application of 2 t compost + 10 kg N through urea recorded significantly highest mung bean grain yields (937.2 kg ha^{-1}) and was at par with other two treatments, viz., 2 t compost + 1 t gliricidia loppings (934 kg ha^{-1}) and 1 t Gliricidia loppings + 10 kg N through urea (926 kg ha^{-1}).
- When compared to control, the percent increase in mungbean grain yields under all the nutrient management treatments were: T3 = 2 t compost + 10 kg N through urea (61.9%) = T5 = 2 t compost + 1 t gliricidia loppings (61.3%) = T4 =1 t Gliricidia loppings + 10 kg N through urea (60.0%) > T2 = 20 kg N through urea (46.9%).
- The long-term yield trends of mung bean as influenced by tillage and INM treatments revealed that after tenth year of the study, the performance of reduced tillage on an average, was almost near to that of conventional tillage. This trend indicated that in case of legume like mung bean, the probability of success of reduced tillage is quite higher in rainfed Alfisol soil which is susceptible to hard setting and compaction. Hence, this finding raises the hope of success of reduced tillage practices in rainfed semi-arid tropical soils.

Sustainability Yield Indices (SYI) and Agronomic Efficiency (AE)

- For sorghum crop, the sustainability yield indices varied from 0.27 to 0.67 while the agronomic efficiency ranged from 18.1 to 23.8 kg grain kg^{-1} N across the management treatments under both conventional and reduced tillages. When averaged over the treatments, conventional tillage maintained the highest SYI (0.57) as well as agronomic efficiency (17.2 kg grain kg^{-1} N) compared to minimum tillage with an average SYI of 0.47 and agronomic efficiency of 14.7 kg grain kg^{-1} N. When averaged over the tillage effects, application of 2 t Gliricidia loppings + 20 kg N through urea maintained the highest SYI (0.60) as well as agronomic efficiency (21.2 kg grain kg^{-1} N) followed by other treatments. Among all the treatments, practice of conventional tillage + application of 2 t Gliricidia loppings + 20 kg N through urea in case of sorghum crop recorded significantly highest SYI (0.67) as well as AE (23.8 kg grain kg^{-1} N).
- For mungbean crop, the sustainability yield indices varied from 0.26 to 0.52 while the agronomic efficiency varied from 13.0 to 19.3 kg grain kg^{-1} N across the management treatments under both conventional and minimum tillage plots. Similarly, in case of mung bean also, when averaged over the treatments, conventional tillage maintained higher SYI (0.47) as well as agronomic efficiency (13.7 kg grain kg^{-1} N) as compared to minimum tillage which maintained SYI of 0.39 and AE of 12.9 kg grain kg^{-1} N.
- When averaged over the tillage effects, both application of 2 t compost + 1 t gliricidia loppings as well as 2 t compost + 10 kg N through urea more or less maintained similar level of SYI and AE compared to other treatments. Among all the treatments, practice of conventional tillage + 2 t compost + 1 t gliricidia loppings maintained higher SYI (0.52) while practice of conventional tillage +2 t compost + 10 kg N through urea maintained higher agronomic efficiency (19.2 kg grain kg^{-1} N) under mung bean crop.

Assessment of soil quality

- Based on the series of analytical data screening steps, available N, Zn, Cu, MBC, MWD and HC were declared as the key indicators for Alfisol under sorghum - mung bean system under conventional and reduced tillage. The SQI varied from 0.66 (control) to 0.86 (4 Mg compost + 20 kg N through urea) under conventional tillage, while under reduced tillage, it varied from 0.66 (control) to 0.89 (4 Mg compost + 2 Mg gliricidia loppings).
- Tillage alone did not show any significant effect on SQI, while the conjunctive nutrient use treatments significantly influenced the SQI in these SAT Alfisols. Among all the treatments, when averaged over tillage, application of 4 Mg compost + 2 Mg gliricidia loppings showed the highest SQI (0.87) followed by 2 Mg gliricidia loppings + 20 kg N through urea (0.84) which was at par with 4 Mg compost + 20 kg N through urea (0.82).

- The interaction effects of tillage and conjunctive nutrient use treatments were also found significant on SQI. On an average, under both CT and RT, the sole organic treatment out-performed in aggrading the soil quality to the extent of 31.8 % over control. The conjunctive nutrient use treatments aggraded the soil quality by 24.2 to 27.2 %, while the sole inorganic treatment could aggrade only to the extent of 18.2 % over the control.
- Interestingly, even the control which did not receive any N input in the form of treatment, except phosphorus, also maintained SQI of as high as 0.66. This may be attributed to the beneficial effect of legume crops grown in rotation with cereals, as various rotations, mainly cereal/legumes, combined with reduced tillage, could influence soil organic matter and associated aggregation and related hydraulic properties. In the present study, the overall order of superiority of the treatments from the viewpoint of soil quality indices was: T5>T4 = T3> T2>T1.
- The order of importance of the key indicators in influencing soil quality was MBC (0.41) = available N (0.41) > DTPA- Zn (0.37) > DTPA- Cu (0.12) > HC (0.09) > MWD (0.04) with a corresponding contribution of 28.5%, 28.6%, 25.3%, 8.6%, 6.1% and 2.9% respectively in these soils. This showed that these key indicators have considerable role to play in influencing various soil functions and in turn the functional goals.

Carbon pools as influenced by INM and tillage practices under sorghum- green gram strip cropping after eight years of study (during 2006)

- After eight years of the study, various pools of carbon viz., organic carbon, inorganic carbon, microbial biomass carbon, oxidizable carbon, particulate organic carbon and total carbon as influenced by tillage and INM treatments were estimated using standard procedures.
- Irrespective of the treatments, minimum tillage plots recorded significantly higher total organic carbon (TOC) of 6.1 and 6.0 g kg^{-1} at both surface and subsurface layers than the conventionally tilled plots. When averaged over tillage, sole application of organics viz., 4 t compost + 2 t gliricidia loppings recorded the highest organic carbon content of 6.4 and 6.2 g kg^{-1} at surface and sub surface depths respectively. In this experiment, tillage did not show any significant influence on the microbial biomass carbon content at both surface and subsurface depths.
- The INM treatments had significant influence on $KMnO_4$ oxidizable carbon (LC) at the surface depth only. Among all the treatments, 2 t gliricidia loppings + 20 kg N through urea recorded the highest oxidizable carbon of 310.3 mg kg^{-1} which was at par with 4 t compost + 2 t gliricidia loppings (299.7 mg kg^{-1}) at surface depth.

- Particulate organic matter (POC) is a fraction of soil organic matter (SOM) that has the potential to serve as an indirect measure of soil health. This fraction plays an important role in soil aggregation either directly or indirectly by serving as a substrate for microbial activity. It is an important measure of soil health because its turn over time allows enough sensitivity to detect changes within a few years.
- Tillage showed significant influence on the particulate organic carbon at surface depth only but not at sub-surface depth. Among the treatments, when averaged over tillages, 4 t compost + 2 t gliricidia loppings recorded significantly highest amount of particulate organic carbon content of 4.5 g kg^{-1} at surface depth while under subsurface depth, 4 t compost + 20 kg N through urea recorded the highest particulate organic carbon content of 4.0 g kg^{-1} respectively.
- In low tillage, POC constituted 63.49 to 74.59 % of total organic carbon (TOC) in surface soil layer (0-5cm) and 48.51 to 77.84 % in subsurface soil layer (5-20 cm). In conventional tillage, the corresponding contribution of POC was 68.52 to 71.22 % and 54.13 to 73.78 % in surface and subsurface depths respectively.

Enzymatic activity as influenced by INM and tillage practices under sorghum- green gram strip cropping (during 2006)

- Minimum tillage proved significantly superior in influencing the dehydrogenase activity in the soils compared to conventional tillage. In minimum tillage, the dehydrogenase activity was 3.83 and 3.34 µg TPF g^{-1} hr^{-1} under surface and subsurface depths respectively.
- Among the treatments, when averaged over the tillage, 2 t Gliricidia loppings + 20 kg N through urea recorded significantly highest dehydrogenase activity of 4.5 µg TPF g^{-1} hr^{-1} which was at par with 4 t compost + 2 t gliricidia loppings (4.3 µg TPF g^{-1} hr^{-1}) at surface depth.
- Sulphatase enzyme has been reported to help in releasing plant available $S0_4$ from organic matter. Tillage did not influence the arylsulphatase activity, whereas, treatments had significant effect Significantly highest activity of arylsulphatase was recorded in 4 t compost + 20 kg N through urea (57.71 µg PNP g^{-1} hr^{-1}) at surface depth, while 2 t Gliricidia loppings + 20 kg N through urea showed significantly highest arylsulphatase activity (55.70 µg PNP g^{-1} hr^{-1}) at subsurface depth.
- The results of the present study will be useful in identifying most effective soil-nutrient management and tillage treatment for further recommendation. In the present study, we are focusing on long term experiments across the rainfed agro-ecology as well as farmers

fields. The data so generated from both the situations would be effectively utilized for recommending soil-nutrient management strategies.

Objective 3: To study the response of sorghum-cowpea system to graded level of surface residue application under minimum tillage in Alfisol and effects on carbon storage.

Effect on Crop yields

- Sorghum grain yields in the first year of the experiment varied from 1396 to 1549 kg ha^{-1} and did not show much significant effect of different treatments. However, application of 6 t ha^{-1} of sorghum stover recorded the highest grain yield of 1549 kg ha^{-1} followed by application of 2t ha^{-1} of sorghum stover (1501 kg ha^{-1}).
- Since, this experiment has been planned on long-term basis to sequester/ store more and more carbon by making the soil as a sink, the intensive soil studies have been planned in the future. The CO_2 fluxes emitted through soil respiration was also periodically assessed.
- During the second year, the cowpea biomass yield was severely affected by hard setting and compaction due to zero tillage and varied from 228 to 319 kg ha^{-1}.
- The highest yield of above ground dry biomass of cowpea was recorded in plots which received of 4 t ha^{-1} of sorghum residue as surface application which was at par with 2 t ha^{-1} of sorghum residue (312 kg ha^{-1}). Horse gram grain and husk yields were significantly influenced by different residue levels and varied from 196 to 290 kg ha^{-1} and 126 to 179 kg ha^{-1} respectively.
- Sorghum residue applied @ 6 t ha^{-1} did not adversely affect the yield of the second crop and recorded the highest horse gram pod yield (468 kg ha^{-1}), grain yield (290 kg ha^{-1}) and husk yield (179 kg ha^{-1}). This treatment was followed by 4 t ha^{-1}. Weed growth and less water intake in the profile under zero tillage adversely affected the crop. Further, the less aeration of the root zone due to zero tillage also might have affected the plant growth.
- During the third year the sorghum grain yields varied from 1878 to 2242 kg ha^{-1} across the treatments. Surface application of 6 t ha^{-1} of sorghum residue recorded significantly highest sorghum grain yield of 2242 kg ha^{-1} which was at par with application of 4 t ha^{-1} of sorghum residue (2020 kg ha^{-1}).
- It was interesting to note that the increase in sorghum grain yield with surface application of 6 t ha^{-1} of sorghum residue and 4 t ha^{-1} of sorghum residue were 19.8 % and 7.98% respectively over no residue application (control). This indicated the importance of surface residue management in these moisture stressed hard setting soils. The beneficial effects of surface applied residues could be on several accounts such as reducing the water losses due to evaporation, keeping the soil temperature low, enhancing the microbial activity,

more recycling of nutrients, protecting the soil from water erosion by way of intercepting the rain drops, etc.

- ❖ During the fourth year application of sorghum crop residue as surface mulch in combination with N @ 30 kg ha^{-1} and 30 kg P_2O_5 ha^{-1} under minimum tillage conditions significantly increased the cowpea (C 152) grain yield with sorghum residue applied as surface mulch @ at 4t ha^{-1}. The increase in grain yield of cowpea with residue application @ 2, 4 and 6 t ha^{-1} was to the tune of 20.7, 56.0 and 33.9% respectively over control.
- ❖ Carbon stocks as influenced by residue loading, minimum tillage, crop stubble retention and cropping system will be computed after fifth year of the study.

Effect of surface crop residue application on the carbon pools

- ❖ In order to study the influence of surface residue application under conservation tillage on carbon pools viz., microbial biomass carbon (MBC), 0.01 N $KMnO_4$ extractable labile C ($KMnO_4$ - LC), particulate organic carbon (POC), Inorganic C (IC), total organic carbon (TOC), soil samples from two depths (0-5, 5-20) were collected after the harvest of the 1st crop of sorghum (2005) and were analyzed using standard procedures. The salient findings of the study were as follows.
- ❖ Based on the data generated after the 1st year of the experiment, it was observed that, except microbial biomass carbon, the other pools were not significantly influenced by the application of various levels of sorghum residues + 60 kg N ha^{-1} applied to previous crops + minimum tillage at both surface (0-5 cm) and sub-surface (5-20 cm) depths.
- ❖ Total Organic carbon (TOC) ranged from 4.2 to 5.2 g kg^{-1} at 0-5 cm depth and 3.8 to 4.8 g kg^{-1} at 5-20 cm depth. Whereas, inorganic carbon in the corresponding soil depths varied between 2.3 to 2.6 g kg^{-1} and 2.3 to 2.6 g kg^{-1} respectively. Interestingly, organic carbon content decreased in the lower depth while inorganic carbon was relatively higher.
- ❖ Microbial biomass carbon (MBC) is an important indicator of soil quality and is a measure of the living component of soil organic matter, except macro fauna and plant roots. In the present study, it ranged from 89.47 to 177.11 μg g^{-1} of soil at 0-5 cm depth and 76.93 to 167.83 μg g-1 of soil at 5-20 cm depth. Among the residue levels applied to the first crop (sorghum), application of 6 t ha^{-1} of sorghum stover recorded significantly highest microbial biomass carbon of 177.11 and 167.83 μg g^{-1} of soil at 0-5 and 5-20 cm respectively. The content of MBC in plots amended with 2 and 4 t ha^{-1} of residue almost remained same.
- ❖ The 0.01 N $KMnO_4$ oxidizable organic carbon is considered as a good measure of labile carbon or active carbon in soil. In this study, it ranged from 309.39 to 344.34 and 299.16

and 340.39 μg g^{-1} of soil at 0-5 and 5-20 cm depths respectively, and was not significantly affected by the management treatments.

- Similarly, particulate organic carbon (POC) and total carbon (TC) in the soils were also not significantly affected by the management treatments. However POC contents varied between 3.1 to 3.8 g kg^{-1} at 0-5 cm depth and 2.8 to 3.4 g kg^{-1} at 5-20 cm depth. Data indicated that POC content was relatively higher in surface layer than sub surface layer. It constituted about 63.49 to 74.49 and 48.51 to 77.84 % of TOC in surface and sub surface respectively.
- The extent of TC was to the tune of 6.5 to 7.8 and 6.3 to 7.4 g kg^{-1} at 0-5 and 5-20 cm depths respectively. Except inorganic carbon, all other carbon pools tended to decrease in sub-surface soil layer.

Effect of residue application on soil enzyme activity

- Soil enzymes are considered as one of the important biological soil quality indicators sensitive to management. Considering this, besides dehydrogenase, arylsulphatase, urease and phosphatases were studied during the period under report. Activity of all the enzymes studied was found to be significantly influenced by the management treatments and the data indicated the reduction in the activity of these enzymes in the lower depth (5-20 cm) of the soil compared to the surface 0-5 cm depth.
- Application of 6 t ha^{-1} of sorghum residue recorded the highest dehydrogenase assay of 2.49 at 0-5 cm depth, which was followed by the application of 4 t ha^{-1} of sorghum residue, while the control plot recorded the lowest assay. At 0-5 cm depth, significantly highest arylsulphatase activity of 174.41 μg PNP g^{-1} hr^{-1} was recorded under sorghum residue application @ 6 t ha^{-1} followed by 4 t ha^{-1}.
- Surface application of 6 t ha^{-1} of sorghum residue recorded the highest urease activity of 62.01 and 53.55 μg NH4 g^{-1} hr^{-1} at 0-5 and 5-20 cm depths respectively, which was followed by that of 4 t ha^{-1} of sorghum stover.
- Studies indicated that acid phosphatases (Ac-P) ranged from 179.8 to 549.5 and 128.1 to 458.2 μg PNP g^{-1} hr^{-1} at 0-5 cm and 5-20 cm depths respectively across the treatments. The significant highest Ac-P activity of 549.50 and 458.20 μg PNP g^{-1} hr^{-1} was recorded under surface application of 6 t ha^{-1} sorghum residue at both the depths respectively, followed by 4 t ha^{-1} of sorghum residue application. Application of 6 t ha^{-1} sorghum residue accounted for an increase of 205.57 % and 257.69 % over control at 0-5 cm and 5-20 cm depths respectively.

- ❖ The alkaline phosphatase activity (Alk-P) showed a trend similar to Ac-P activity. The significantly highest Alk-P activity of 400.3 and 328.0 μg PNP g^{-1} hr^{-1} was recorded under application of 6 t ha^{-1} sorghum residue at 0- 5 cm and 5- 20 cm depths respectively followed by 4 t ha^{-1} of sorghum residue application. Application of 6 t ha^{-1} sorghum residue recorded an increase of 376.2 % and 514.7 % over control in 0-5 cm and 5-20 cm depths respectively.
- ❖ The present study clearly indicated that acid and alkaline phosphatases activity increased with graded levels of residue application and tended to decrease with depth.

Effect of residue application on CO_2 emissions

- ❖ The CO_2 emissions were measured in this experiment which received sorghum residue @ 0, 2, 4 and 8t ha^{-1} as surface mulch as treatments and 60 Kg N ha^{-1} as uniform dose to sorghum crop in all the plots. Different level of residues significantly influenced the CO_2 emission. The emission rates increased with the amount of residue applied up to 4 t ha^{-1}on most of the Julian dates (between 315th to 30th Julian day). These studies will be of immense importance in computation of C balance, sink and stocks in soil and to develop management strategies for enhancing the level of SOC in these soils, which are mostly at the verge of degradation. The methods of measurements of CO_2 flux need to be improved using automatic CO_2 Flux Meters using IRGA (infrared gas analyzers) technique. These studies will be further continued.

Objective 4: To study the influence of conjunctive use of residues and graded levels of N on crop yields and predominant N pools under sorghum-castor system.

Sorghum grain yields

- ❖ Since the initiation of the experiment (1995), sorghum and castor were grown in rotation. During the period from 1995 to 2008, sorghum crop was grown during the years 1995, 1997, 1999, 2001, 2003, 2005, and 2007. In the year 2003, crop failed due to severe drought spell.
- ❖ Of the tillages, on an average, conventional tillage out performed over the minimum tillage in recording the sorghum grain yields during all the years. The average sorghum grain yields under conventional tillage were 1248 kg ha^{-1} while under minimum tillage it was 957 kg ha^{-1} amounting to 30.4% increase over the minimum tillage.
- ❖ Among the residues applied, gliricidia application outperformed the other two residue treatments and recorded sorghum grain yields to the extent of 1156 kg ha^{-1}, followed by sorghum stover application (1094 kg ha^{-1}) and no residue application (1058 kg ha^{-1}).

- Average sorghum grain yields showed a tremendous response towards the application of N levels and it was observed that the yields increased with increase in N level gradient. The average sorghum grain yields with the respective N levels were: 1425 kg ha^{-1} with 90 kg ha^{-1}, 1292 kg ha^{-1} with 60 kg N ha^{-1}, 1067 kg ha^{-1} at 30 kg N level while at 0 level, the yields were only to the extent of 626 kg ha^{-1}.
- The increase in sorghum grain yields over the 0 level was to the extent of 70.4%, 106.4 % and 127.6 % at 30, 60 and 90 kg levels respectively.

Castor crop yields

- During the period from 1995 to 2008, castor crop was grown only during the years 1996, 1998, 2000, 2002, 2004, 2006 and 2008. Statistical analysis of the data revealed a significant influence of years, tillage, residues as well as the N levels on castor pod yields. Of the tillages, on an average, conventional tillage out performed over the minimum tillage in recording the castor bean yields during all the years.
- The average castor bean yields under conventional tillage were 826 kg ha^{-1} while under minimum tillage it was 526 kg ha^{-1} amounting to 57.0 % increase over the minimum tillage. Among the residues applied, gliricidia application outperformed the other two residue treatments and recorded castor bean yields to the extent of 726 kg ha^{-1}, followed by sorghum stover application (666 kg ha^{-1}) and no residue application (638 kg ha^{-1}).
- Average castor bean yields showed a tremendous response towards the application of N levels and it was observed that the yields increased with increase in N level gradient. The average castor bean yields with the respective N levels were: 876 kg ha^{-1} with 90 kg ha^{-1}, 749 kg ha^{-1} with 60 kg N ha^{-1}, 639 kg ha^{-1} at 30 kg N level while at 0 level, the yields were only to the extent of 441 kg ha^{-1}.
- The increase in castor bean yields over the 0 level was to the extent of 44.9 %, 69.8 % and 98.6 % at 30, 60 and 90 kg levels respectively.
- On an average, conventional tillage maintained higher grain yields of sorghum and castor to the tune of 30.4% and 57.0% respectively over minimum tillage. Among the residues, gliricidia application out performed the other two residues treatments in case of both the crops. Response of both the crops to graded levels of N application was tremendous. The highest yields of sorghum (1425 kg ha^{-1}) and castor (876 kg ha^{-1}) were recorded with application of 90 kg N ha^{-1}.

Influence on CO_2 emissions through soil respiration

- Monitoring of CO_2 fluxes emitted through soil respiration was undertaken after harvest of crop in this eleven year old (during 2005) experiment with sorghum-castor as crop rotation. CO_2 emission was significantly influenced by residues and N levels. However, significant effect of tillage was not seen on some of the Julian days. Irrespective of N levels and residues, in minimum tillage plots, relatively higher CO_2 emission (232.0 mg CO_2 m^{-2} hr^{-1}) was recorded compared to conventional tillage (216.0 mg CO_2 m^{-2} hr^{-1}). This may be attributed to higher microbial activity because of more biomass availability for microbial respiration. Moreover, the observations were recorded after 5 months of the tillage treatments (or sowing of crop) i.e. immediately after harvest of the crop. Presumably, by that time, the oxidative influence of conventional tillage might have come down because of compaction, etc.

Effect of management components on soil nitrogen pools

- The long-term influence of tillage, residues and N levels on various inorganic and organic N factions was studied under various treatments in sorghum-castor rotation. Among the inorganic fractions, exchangeable ammonical nitrogen varied from 17.1 to 42.1 mg kg^{-1} while the nitrate-N varied between 3.89 to 13.4 μg g^{-1} of soil across the management treatments.
- Significantly highest ammonical N was observed under conventional tillage (35.5 mg kg^{-1}) than under minimum tillage (26.8 mg kg^{-1}). Residue application significantly improved inorganic N fractions over 'no residue' application. Fertilizer N application significantly increased ammonical and nitrate N.
- Total hydrolyzable N varied from 333.6 to 648.9 mg kg^{-1} across the management treatments and residue application significantly increased total hydrolyzable N in soils. On an average, total hydrolyzable N was 508.5, 481.6 and 440.4 mg kg^{-1} under sorghum residues, gliricidia loppings and 'no residue' plots respectively. Fertilizer N also played an important role in improving the total hydrolyzable N pool and it was 577.2 mg kg^{-1} of soil @ 90 kg ha^{-1}.
- The order of contribution of different hydrolyzable fractions towards total hydrolyzable N was: amino acid N (51.5%) > unidentified N (21.4 %) > hydrolyzable ammonical N (13.01%) > hexosamine N fraction (8.41 %). Conspicuous influence of the application of residues and N levels on hexosamine N was observed while the influence of tillage and other interaction effects was not noticed. Tillage, residues as well as N levels significantly influenced the amino acid N fraction. On an average, significantly highest amino acid N content was observed under minimum tillage (265.0 mg kg^{-1}) followed by conventional tillage (225.7 mg kg^{-1}).
- Unidentified N fraction was significantly highest under conventional tillage (148.7 mg kg^{-1}) while under minimum tillage it was 110.2 mg kg^{-1}. Among the residues, on an average,

the unidentified N fractions were significantly lower under application of gliricidia loppings (117.0 mg kg^{-1}) followed by 'no residue' application (127.5 mg kg^{-1}) while it was slightly higher under sorghum stover application (143.7 mg kg^{-1}).

- Fixed ammonical N, which represent the nitrogen retained in the clay lattices, varied between 97.8 to 183.8 mg kg^{-1} across the management treatments and was significantly influenced by tillage, residue application as well as varying N levels.

Outcome and practical utility of the study:

The present study has helped in creating a huge data base on the long and medium term influences of soil and nutrient management practices on soil quality indicators under diversity of soil and climatic condition in rainfed agroecology across the country which was earlier , lacking. Study has also helped in identifying the key indicators of soil quality for different soil types, climatic conditions and cropping system across the rainfed regions in the country which can be utilized further for improving soil quality. Another out come of this study is that it has helped in identifying best soil and nutrient management practices from the view point of improving soil quality and to improve crop yields on sustainable basis. At dryland centers soil quality assessment studies were undertaken in some of the farmer's fields also. Similarly, these studies were under taken for more than 300 farmers in Ranga Reddy district of Andhra Pradesh. Soil health reports were issued to these farmers for chemical quality parameters which would be useful for them in planning fertilizer applications. The concept and methodology adopted in this study is quite new and is comparable with that being followed at International level. The approach and findings of these studies will be highly useful to researchers, students, farmers, NGOs, state agricultural departments, officers of soil testing laboratories in the country, land managers and policy planners.

The outcome of the project will bring new dimensions in the land care and soil quality improvement program of the country. Studies conducted in Alfisol at Hyderabad have helped in identifying the best low cost INM treatments using farm based organics. Further, lot of valuable information has been generated through field experiments focusing on conservation agricultural practices on improvement of soil quality in Alfisol soils which are low in fertility, low in organic matter, having low clay content, poor in water retention and are susceptible to crusting, hard setting and compaction. Despite our all efforts, there are few limitation and gaps in the study which will be removed in the second phase of the Fellowship.

Funds have been efficiently utilized. Over and above, it was an excellent support and opportunity for encouraging the research on specialized themes. This is probably a great visionary step of

Indian Council of Agricultural Research to support the advanced specialized themes of the research through such National Fellowships. I gratefully acknowledge this support.

(K.L. Sharma)
Principal Scientist &
National Fellow

Hyderabad
September 7, 2009

Consolidated Progress Report

1. **Name of the Institute:** **Central Research Institute for Dryland Agriculture**
2. **Address** **Saidabad, Santhoshnagar, Hyderabad-59.**

3. **Name of the Scheme:** **"Assessing soil quality key indicators for development of soil quality index using latest approaches under predominant management practices in rainfed agroecology"**

(Revised title in institute SRC: "Restoration of soil quality through conservation agricultural management practices and it's monitoring using Integrated Soil Quality Index (ISQI) approach in rainfed production system (s)")

4) Significant research achievements

4.1. Introduction, background and objectives

4.1.1. Rainfed agriculture - World perspective

Across the world, rainfed agriculture covers about 4888 million hectares (m ha) of land. Out of which 2124 million hectares falls under semi-arid regions, 2180 million hectares represent arid regions and 581 million hectares area is in very extreme arid regions. These rainfed regions comprise of diversity of soil types viz. Alfisols (307m ha), Aridisols (1657 m ha), Entisols (1915 m ha), Mollisols (547 m ha), Vertisols (188 m ha) and different miscellaneous and mixed soils (290 m ha). Rainfed soils are recently developed soils and mainly characterized by less weathering which is mostly, physical weathering. The soils are mostly low in soil organic carbon (SOC) (0.5 to 5.0 g kg^{-1}) especially in surface horizon. The concentrations of soil inorganic C (SIC) is quite high especially in the calcic and petrocalcic horizon, which also comprises of high concentration of secondary and pedogenic carbonates. To improve the production potential of these soils, soil organic and inorganic C contents need to be improved which can be primarily achieved by improving the water and nutrient use efficiencies by reducing the losses and improving the land cover and biomass production. Some of the potential options could be conservation tillage, surface residue management and mulch farming, inclusion of cover crops in the crop rotations, mixed farming, cropping, agroforestry, ley farming and practicing integrated nutrient and pest management approaches. Other options could be the management of grazing land and forests, controlling fires and stopping burning of crop residues. The biggest constraints in building up of organic matter in these soils are, low precipitation, extremely high temperature, low clay content in soil and low biomass productivity due to miserably low level of inherent soil fertility and low level of nutrient use because of high degree of poverty (Lal, 2004).

4.1.2. Rainfed agriculture - Indian perspective

The predominant soil orders that represent rainfed agriculture are Alfisols, Inceptisols, Entisols, Vertisols, Oxisols and Aridisols. Out of the total geographical area of 328.28 m ha, Entisols constitute 24.37 % (80.1 m ha), Inceptisols 29.13 % (95.8 m ha), Vertisols 8.02 % (26. 3 m ha), Aridisols 4.47 % (14.6 m ha), Mollisols 2.43 % (8 m ha), Ultisols 0. 24 % (0.8 m ha), Alfisols 24.25 % (79.7 m ha), Oxisols 0.08 % (0.3 m ha) and the non-classified soils constitute 7.01 % (23.1 m ha) (Prasad and Biswas, 1999). In Indian subcontinent, out of an estimated 142.2 million ha net cultivated area, only about 33.3% (47.4 million ha) is irrigated. The irrigated area produces about 56% of India's total food requirements. The remaining 44% of the total food production is contributed by 95.8 million ha (66.7%), which is rainfed. Statistics reveal that rainfed agriculture supports about 40% of the India's more than 1000 million population. It is in the rainfed belt where most of the coarse cereals (91%), pulses (91%), oilseeds (80%) and cotton (65%) are grown. These data emphasize the important role played by rainfed agriculture in the country's economy and food security. The yield curve in most of the crops in irrigated areas has touched the plateau because of stagnated response to the added inputs. Therefore, it is anticipated that, if at all another green revolution were expected in Indian agriculture, it would come from grey areas only. Considering the gap between possible potential yield of rainfed crops and their actual realized yields, there are tremendous scopes to enhance the yield levels. To cite an example, the possible potential yield of sorghum in researchers plots is about 3970 kg ha^{-1}, whereas, the average level of yield in verification trails was found to be 2090 kg ha^{-1}. The average yield level in rural farms was as low as 370 kg ha^{-1} (Kanwar, 1999). This demands for a strategic planning for research and development in dryland agriculture.

The rainfed areas are extensively spread in the country from north to south and east to west. These areas can be broadly classified into arid, semi-arid and dry sub-humid. The arid areas forming 19.6% of the total geographical area (329 million ha) are characterized by low and erratic rainfall (<500mm) and light textured soils. The growing season is very short (up to 75 days) with millets and short duration pulses dominating the cropping systems. Livestock farming forms an important part of the arid ecosystem. The semiarid areas can be further classified into dry and wet. Dry semiarid areas form 12% of the geographical area and receive a mean annual rainfall of 500-700 mm with a growing season of 75-100 days. The soils in the north of the country are loamy sand, light sandy loam and medium black soils, whereas in peninsular part, shallow and medium black soils are predominant. The wet semiarid region constituting 25.9% of the geographical area receives mean annual rainfall to the tune of 750-1100 mm with a growing season up to 120 days. This zone has sandy loam and loam soils in the north, medium to deep black soils in the central part, and red and medium to deep black soils in the south. The crops and cropping systems are quite diverse in the semiarid part of the country depending on the soil type and the length of the growing season. Sorghum, cotton, soybean, groundnut and pulses are the major crops grown in this zone. The dry sub-humid areas constitute 21.1% of the geographical area and receive mean annual rainfall of 1100-1600 mm. The high rainfall in these areas provides opportunity for water harvesting. Dominant soils in this climatic zone are red loams, laterites, and alluvial and deep black soils. Rainfed rice is the predominant crop followed by pulses and oilseeds.

The land use in drylands is quite diverse with a variety of crops, cropping systems, agroforestry and livestock farming. The rainfed ecosystem suffers from the problems of (i) frequent droughts due to high variability in the quantum and distribution of rainfall, (ii) poor soil health due to continued degradation and inadequate replenishment of nutrients removed by crops, (iii) low animal productivity due to acute scarcity of green fodder and (iv) low risk bearing capacity of farmers due to socio-economic constraints, credit availability, and infrastructure (Singh, 1998). Among the biophysical constraints, poor soil quality is considered as one of the important limitations in getting desired level of crop yields. Across the rainfed agroecology, soils are mostly under the grip of degradative processes.

Soils in the rainfed regions constitute diverse orders with extreme variability in origin, parent material, water retention and nutrient status. In addition to the parent material, climatic variables like rainfall, temperature and sunshine influence the type and key properties of soils in a given region. Because of erosion losses and high temperature mediated fast decomposition, most of these soils are exhausted of organic matter which is the storehouse of many plant nutrients and which strongly influences the physical and biological properties of soils. Consequent to low organic matter, soils are poor in soil fertility and physical and biological properties. Ultimately, overall functional and productive capacity of these soils is low. In rainfed agro-ecosystem, diversity of management practices such as different kinds of tillage, varying levels of fertilizers conjunctive use of organics and inorganic sources of nutrients, application of herbicides, different crop rotations, mono-crops, intercropping with legumes etc., are being followed on long-term basis in experimental stations. At the same time, farmers are also following variety of management practices. Some of these practices are quite beneficial and aggradative in nature, whereas, others are degrading.

4.1.3. Land degradation and soil quality deterioration - causes and effects

Land degradation and soil quality deterioration are one of the several reasons of agrarian stagnation and perpetuation of hunger and malnutrition. In India, the total degraded area accounts to 120.7 m ha, of which 73.3 m ha was affected by water erosion, 12.4 m ha by wind erosion, 6.64 m ha by salinity and alkalinity and 5.7 m ha by soil acidity. The problem is more severe in rainfed areas. The predominant causes of land degradation and soil quality deterioration could be: (i) washing away of topsoil and organic matter associated with clay size fractions due to water erosion resulting in a 'big robbery in soil fertility', (ii) intensive deep tillage and inversion tillage with moldboard and disc plough resulting in a) fast decomposition of remnants of crop residues which is catalyzed by high temperature, b) breaking of stable soil aggregates and aggravating the process of oxidation of entrapped organic C and c) disturbance to the habitat of soil micro flora and fauna and loss in microbial diversity, (iii) dismally low levels of fertilizer application and widening of removal-use gap in plant nutrients, (iv) mining and other commercial activities such as use of top soil for other than agricultural purpose, (v) mono cropping without following any suitable rotation, (vi) nutrient imbalance caused due to disproportionate use of primary, secondary and micronutrients, vii) no or low use of organic manures such as FYM, compost, vermi-compost and poor recycling of farm based crop residues because of competing demand for animal fodder, (vi) no or low green manuring as it competes with the regular crop for date of sowing and other resources in rainfed regions, (vii) poor nutrient use efficiency attributing to nutrient losses due to leaching, volatilization and denitrification, (viii) indiscriminate use of other agricultural inputs such as herbicides, pesticides, fungicides, etc., resulting in poor soil and water quality, (viii) water logging, salinity and alkalinity and acid soils.

Among the degradative processes, soil erosion has been considered as a threat to the soil resource long before the concept of soil quality was introduced. Erosion causing vertical as well as lateral mixing of soil constituents leads to important changes in soil properties and ultimately soil quality. Due to the preferential erosion of fine grained sand and coarse silt, wind erosion generally results in a gradual coarsening of the top layer leading to the serious degradation for several reasons. First, the soils nutrients are largely situated in the fine particle fractions. Secondly, due to the evacuation of these fractions, the water economy in the topsoil degrades. The coarse sandy top layer dries quickly, and this not only affects the crops but also increases the soils vulnerability to subsequent wind erosion. Thirdly, a lower silt and clay content enhances the eluviation of humus and other soil constituents and promotes acidification. Fourthly, to remain fertile, degraded sandy topsoil requires sufficient amount of fertilizer, which is much less the case for topsoil rich in silt in clay (Govers *et al*., 2004).

Erosion processes also influence the loss of organic matter. Since most of the humic matter in soil is directly or indirectly bound to the finer soil fractions (< 150 µm), soil particles lost in wind erosion are normally characterized by a much higher organic matter (OM) content than their parent soil. Medium and fine textured soils are especially vulnerable to this type of degradation. A small amount of soil organic matter exists in the form of plant residues. Because of their very low density, these residues are very easily eroded by wind and water. Their rapid evacuation precludes their transformation into humus, which could have been incorporated into the upper soil layer. Furthermore, as the organic matter is strongly bound to the clay fraction, the enrichment of OM in water-eroded sediment is generally directly proportional to its enrichment in clay (Govers *et al*., 2004).

Apart from organic matter, many other soil constituents, such as N, P, K and other nutrients are removed from the parent soil due to wind and water erosion. Analyses of wind blown sediments clearly demonstrate the enrichment of these elements in the eroded particles. Despite the fact that the highest nutrient fluxes are measured in the saltation layer, the suspended fraction is more important with respect to soil degradation, because saltation results only in a local redistribution, whereas most nutrients in suspension leaves the parent field. In addition, the analysis of runoff samples shows a strong preferential export of P by water erosion, as this nutrient is strongly bound to the clay and OM fractions (Govers *et al*., 2004). The magnitude of nutrient mining has also become huge in many areas. Accelerated erosion and drought have also aggravated the problem of nutrient depletion.

Hence, the adoption of conservation tillage and use of crop residue mulch have proved useful in minimizing soil erosion risks, conserving soil water and reducing drought, recycling plant nutrients, and regulating soil temperature. The beneficial effects of conservation tillage and mulch farming techniques however are soil and ecoregions specific. Another approach i.e. no-till system of crop production is a specific variant of conservation tillage and its success depends on the availability of crop residue mulch, judicious use of chemical fertilizers and adequate weed control measures. This system may take more time to exhibit benefits in soils prone to poor drainage and compaction, and where residue mulch is not available in enough quantity to minimize soil erosion, decrease evaporation losses and regulate soil temperature. No-till affects the agricultural sustainability and environmental quality through its impact on soil properties and processes. Notable among these is soil physical quality as determined by soil structure. Soil structural impacts of no-till and mulch farming may be related to water stable aggregation, mean weight diameter of aggregates and water retention and transmission properties (Lal, 1998).

4.1.4. Need for assessment of soil quality

Increased severe threat of soil degradation has reminded about the need for soil quality evaluation. Therefore, it is desirable to examine the changes caused by different degradation processes that result in decline of soil productivity or soil quality. In order to plan for averting the ill effects of degradative processes, periodical assessment of soil quality is inevitable. Besides this, soil quality assessment could be an effective decision making tool for agriculturalists, land users, decision and policy makers, etc., to develop management practices and strategies to sustain or build up soil quality and also sustain environment. It is considered as the key element of sustainable agriculture, which refers to productivity, economic, social and environmental components of land use systems. Although sustainability issues are much broader than soil quality, the strong emphasis on maintaining the natural resource base ensures that maintaining good soil quality is an integral part of sustainable agriculture (Carter, 2002). Soil quality assessment requires a monitoring system to provide regular surveillance of soil quality attributes or indicators overtime. Soil quality indices are the decision tools that effectively combine a variety of information for multi-objective decision-making (Karlen and Stott, 1994). Soil quality assessment typically includes the quantification of indicators of soil quality. Indicators are the measurable surrogates for processes or end points such as plant productivity, soil pollution and soil degradation (Pankhurst *et al*., 1997). But the interpretation of soil quality indicators requires the experience and skill of the researcher and / or soil manger.

4.1.5. Soil quality and soil health

Similar to air or water, the quality of soil has a profound effect on the health and productivity of a given ecosystem and the environments related to it. Soil quality is often thought of as an abstract characteristic of soils which cannot be defined because it depends on external factors such as land use and soil management practices, ecosystem and environmental interaction, socioeconomic and political priorities and so on (Doran *et al.*, 1996). Perceptions of what constitutes a 'good soil' vary depending on individual priorities for soil function and intended land use. 'Soil quality' and 'soil health' are terms that are generating increasing discussion in the agricultural community. Both these terms encompass a complex, dynamic concept, difficult to define and hard to measure. The term *soil quality* and *soil health* are often used interchangeably in the scientific literature and in general, preferring **"soil quality"** and producers preferring **"soil health".** *"Soil quality*" is the capacity of a specific kind of soil to function within ecosystem and land-use boundaries, to sustain biological productivity, maintain environmental quality, and sustain plant, animal, and human health (Doran and Parkin, 1994). "S*oil health"* is defined as being a state of dynamic equilibrium between flora and fauna and their surrounding soil environment in which all the metabolic activities of the former proceed optimally without any hindrance, stress or impedance from the latter (Goswami and Rattan, 1992). Soil health is considered as the state of the soil at a particular time, equivalent to the dynamic soil properties that change in short term, while soil quality may be considered as soil usefulness for a particular purpose over a long time scale, equivalent to intrinsic or static soil quality. Soil quality lists at least three diverse simultaneous functions that must be optimized to achieve high rating of soil quality viz., to sustain i) plant and animal productivity, ii) maintain or enhance water and air quality, and iii) support human health and habitation. The perception that soil is "living", though disputed by some, results from the observation that number of living organisms in a fertile soil (10 g) can exceed nine billion, one and one-half times of the human population of the earth. Soils form slowly, averaging 100-400 years per centimeter of topsoil, through the interaction of climate, topography, a myriad of living organisms (earthworms, insect, bacteria, fungi, algae, nematodes, animals, plants, human etc.). Thus, the physical and chemical attributes of soil regulate biological activity and interchanges of molecules/ions between the solid, liquid and gaseous phases, which influence nutrient cycling, plant growth, and organic matter decomposition. The inorganic components of soil play a major role in retaining cations through ion exchange and non-polar organic compounds and anions through sorption reactions.

4.1.5a. Soil Quality - Concepts

Soil quality has been defined by many workers in different ways. Soil quality has been defined as the "capacity of the soil to function" (Doran and Parkin 1994; Karlen *et al.*, 1997). Seybold *et al.* (1998) defined the soil quality as '*the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation.'*

Soil function describes what the soil does. The functions are evaluated with respect to their capacity to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation in determining soil quality (Doran and Parkin 1994). Quality with respect to soil can be viewed in two ways: (1) as inherent properties of a soil; and (2) as the dynamic nature of soils as influenced by climate, and human use and management. This view of soil quality requires a reference condition for each kind of soil with which changes in soil condition are compared and is currently the focal point for the term 'soil quality'. The best means to improve or maintain soil quality are, alternative agricultural practices such as crop rotations, recycling of crop residues and animal manures, reduced input of chemical fertilizers and pesticides, and increased use of cover crops and green manure crops, including nitrogen-fixing legumes. Apart from these, conservation tillage has been proved quite promising in improving soil quality. These help to maintain a high level of soil organic matter that enhances soil tilth, fertility and productivity while protecting the soil from erosion and nutrient runoff. Effective implementation of these alternative agricultural practices using a holistic or systems approach requires skilled management and innovativeness by the farmers (Parr *et al.* 1992). In other word, soil quality is a net result of degradative and aggradative practices and processes. Soil quality occupies a pivotal position in this concept and one has to agree that soil quality is the key to agricultural sustainability.

4.1.6. Measuring soil quality using indicators

The soil quality as influenced by management practices can be measured quantitatively using physical, chemical and biological properties of soils as these properties interact in a complex way to give a soil its quality or capacity to function. Thus, soil quality cannot be measured directly, but must be inferred from measuring changes in its attributes or attributes of the ecosystem, referred to as indicators. Indicators of soil quality should give some measure of the capacity of the soil to function with respect to plant and biological productivity, environmental quality and human and animal health. Indicators are measurable properties of soil or plants that provide clues about how well the soil can function. Indicators provide signal about desirable or undesirable changes in land and vegetation management that have occurred or may occur in the future. By measuring key attributes of a system, indicators show the condition and trend of the resource being used (Dalal *et al.* 1999). Sustainability indicators are intended to provide the information that is the basis for a common understanding of what is understood by sustainable systems and a process to monitor trends of such a system. Indicators can be physical, chemical, and biological characteristics. Indicators can be assessed by qualitative or quantitative techniques. After measurements are made, they can be evaluated by looking for patterns and comparing results to measurements taken at a different time or field. Soil quality indicators are important to focus conservation efforts on maintaining and improving the condition of the soil, evaluate soil management practices and techniques, relate soil quality to that of other resources, collect the necessary information to determine trends and determine trends in the health of the nation’s soils. Soil quality is estimated by observing or measuring several different properties or processes. No single property can be used as an index of soil quality.

4.1.7. Important indicators of soil quality

Principal soil properties most affected by soil degradation processes could form the key attributes for soil quality evaluation. Indicators of soil quality may directly monitor the soil, or monitor the outcomes that are affected by the soil, such as productivity, vegetation, water and air. The indicators that directly monitor the soil are grouped as (i) visual, (ii) chemical, (iii) physical and (iv) biological indicators. The indicators that indirectly monitor the soil health are: crop yield/unit area/unit time, plant biomass/unit area/unit time, legume/non legume crop ratio, water use efficiency/unit time, nutrient use efficiency/unit water used/unit time, and produce quality such as cereal grain protein, concentration of toxic elements in food grains, vegetables, fruits etc. Visual indicators of soil health may be obtained from observation or photographic interpretation. Ex: exposure of subsoil, change in soil colour, etc. Visual evidence can be clear indication that soil quality is threatened or changing. Dominant chemical indicators include soil pH, electrical conductivity, adsorption and cation exchange capacity, organic matter, and available nutrients. The other useful indicators, especially those that are needed for plant growth and development can also be included. The comprehensive list of soil quality indicators required to be considered at different levels of management and planning is given in Table 1 as suggested by Singer and Ewing (2000).

Table 1: Soil quality indicators at different levels of soil management and planning

Physical indicators	Chemical indicators	Biological indicators
Field, farm or watershed indicators		
Aeration	Base saturation	Organic carbon
Aggregate stability	percentage	Microbial biomass carbon
Bulk density	Cation exchange	C and N
Clay mineralogy	capacity	Total biomass
Colour	Contaminant	Bacterial
Consistence (dry, moist, wet)	availability	Fungal
Depth of root limiting layer	Contaminant	Potentially mineralizable N
Hydraulic conductivity	concentration	Soil respiration
Oxygen diffusion rate	Contaminant mobility	Enzymes
Particle size distribution	Contaminant presence	Dehydrogenase activity
Penetration resistance	Electrical conductivity	Phosphatase activity
Pore conductivity	Exchangeable sodium	Arylsulphatase activity
Pore size distribution	percentage	Biomass C/total organic carbon
Soil strength	Nutrient cycling rates	Respiration /biomass
Soil tilth	pH	Microbial community fingerprinting

Physical indicators	Chemical indicators	Biological indicators
Structure type	Plant nutrient availability	Substrate utilization
Temperature		Fatty acid analysis
Total porosity	Plant nutrient content	Nucleic acid analysis
Water holding capacity	Sodium adsorption ratio	
Regional or National Indicators		
Desertification	Organic matter trends	Productivity (yield stability)
Vegetative cover	Acidification	Taxonomic diversity at the group level
Water erosion	Salinization	
Wind erosion	Changes in water quality	Species richness/diversity
Siltation or rivers and lakes		Keystone species and ecosystem engineers
Sediment load in rivers	Changes in air quality	
		Biomass, density and abundance

Source: Singer and Ewing (2000)

4.1.8. Role of soil quality indicators in influencing soil processes and functions

Every soil attribute or soil quality indicator has an important role to play in influencing various soil processes and functions. Hence, to understand the changes in processes and functions, quantitative measurement of attributes or indicators is inevitable. The predominant soil physical, chemical and biological attributes or indicators and corresponding processes influenced by them as suggested by Lal (1994) are given in Table 2 & 3.

Table 2: Major soil physical attributes and related processes

Attributes	Processes and soil functions
A. Mechanical	
Texture	Crusting, gaseous diffusion, infiltration
Bulk density	Compaction, root growth, infiltration
Aggregation	Erosion, crusting, infiltration, gaseous diffusion
Pore size distribution and continuity	Water retention, and transmission, root growth and gaseous exchange
B. Hydrological	
Available water capacity	Drought stress, biomass production, soil organic matter content
Non-limiting water range	Drought, water imbalance, soil structure
Infiltration rate	Runoff, erosion leaching
C. Rooting zone	

Attributes	Processes and soil functions
Effective rooting depth	Root growth, nutrient and water use efficiencies
Soil temperature	Heat flux, soil warming activity and species diversity of soil fauna

Source: Lal (1994)

Table 3: Predominant soil chemical, nutritional and biological attributes and related soil processes

Attribute	**Process**
pH	Acidification and soil reaction, nutrient availability
Base saturation	Absorption and desorption, solublization
Cation exchange capacity	Ion exchange, leaching
Total and plant available nutrients	Soil fertility, nutrient reserves
Soil organic matter	Structural formation, mineralization, biomass carbon, nutrient retention
Earthworm population and other soil, macro fauna and activity	Nutrient cycling, organic matter decomposition, formation of soil structure
Soil biomass carbon	Microbial transformations and respiration, formation of soil structure and organo-mineral complexes
Total soil organic carbon	Soil nutrient source and sink, bio-mass carbon, soil respiration and gaseous fluxes

Source: Lal (1994)

4.1.8.1. Chemical indicators of soil quality

Among the set of indicators, pH is one of the important indicator, which influence some of the soil functions. It can provide trends in change in soil health in terms of soil acidification (surface and sub surface) (Moody and Aitken, 1997), soil salinization, electrical conductivity, exchangeable sodium (soil structural stability) (Rengasamy and Olsson, 1991), limitations to root growth, increased incidence of root disease, biological activity, and nutrient availability (e.g. P availability at either high pH>8.5 or low pH <5; Zn availability at high pH >8.5) (Doran and Parkin, 1996). Soil pH trends also provide changed capacity of the soil for pesticide retention and breakdown as well as the mobility of certain pesticides through soil. These processes affect soil health on-farm and have effects beyond farm gate (Karlen *et al.* 1997). Electrical conductivity is a measure of salt concentration and therefore, its measure can provide trends in salinity for both soil and water, limitations to crop growth and water infiltration, and along with pH (indicating soil sodicity), it can be a surrogate measure of soil structural decline (eg. high pH >8.5 and low electrical conductivity, <0.1 dSm^{-1}) (Rengasamy and Olsson 1991).

It is a well-established fact that, the organic matter is fundamental to the maintenance of soil health because it is essential to the optimal functioning of a number of processes important to sustainable ecosystems. Soil organic matter is a source and sink of carbon and nitrogen and partly of phosphorus and sulfur. It affects micronutrient availability through complexation, chelation and production of organic acids, thus altering soil pH. Conversely, it ties up metals present in toxic amounts (e.g. Cu, As, Hg) (Doran and Parkin 1996). Organic matter is essential for good soil structure especially in low clay content soils, as it contributes towards both formation and stabilization of soil aggregates (Dalal and Mayer 1986). Other functions include: contribution to low cation exchange capacity, especially in low clay content soil, pesticide retention (Kookana *et al.* 1998), microbial biodiversity, water retention in sandy and sandy-loam soils, and provision of carbon sink and source for greenhouse gases. Trends in soil organic matter content provide an integrated measure of sustainable ecosystem (Karlen *et al.* 1997). Status of plant available nutrients, for example, N, P, S and K indicate the systems sustainable land use, especially, if the nutrient concentration and availability are approaching but remain above the critical or threshold values. In the long-term, nutrient balance of the system (e.g. Input efficiency =output) is essential to sustainability. Thus, available nutrients are indicators of the capacity to support crop growth, potential crop yield, grain protein content (Dalal and Mayer 1986), and conversely, excessive amounts may be a potential environmental hazard (e.g. algal biomass).

4.1.8.2. Physical indicators of soil quality

Indicators related to physical soil health reflect the capacity to accept, store, transmit and supply water, oxygen and nutrients within ecosystem. This includes monitoring of soil structure through pore size distribution, aggregate stability, saturated hydraulic conductivity, infiltration, bulk density, and surface crust. Rooting depth provides a good indicator of buffering against water, air and nutrient stress. Soil surface cover can be used as an indicator of soil surface protection against raindrop impact, and hence enhanced infiltration, reduced surface crust, and reduced soil erosion and runoff. Soil water infiltration measures the rate at which water enters soil surface, and transmitted through the immediate soil depth (Arshad *et al.* 1996). Rainfall is rapidly absorbed by soil with high infiltration rate, but as the soil structure deteriorates, usually with the loss of organic matter, increase in exchangeable sodium and low electrolyte concentration, infiltration rate of a soil becomes low (Rengasamy and Olsson 1991). This increases the tendency for soil erosion and runoff in sloping soils and water logging in flat soils. Unfortunately, current procedures for measuring infiltration rates are cumbersome, and subject to large errors. A modified disc permeameter could make infiltration rate and hydraulic conductivity a routine procedure (Bridge 1997).

Soil aggregate stability is measure of structural stability and refers to the resistance of soil aggregates to breakdown by water and mechanical force. Aggregate stability is affected by health and quantity of organic matter, types of clays, wetting and drying, freezing and thawing, types and amounts of electrolyte, biological activity, cropping systems and tillage practices (Arshad *et al.* 1996). For monitoring trends in soil health, sampling procedures for aggregate stability need to be standardized. Bulk density varies with the structural condition of the soil. It is altered by cultivation, loss of organic matter (Dalal and Mayer 1986), and compression by animals and agricultural machinery, resulting in compact plough layer. It generally increases with depth in the soil profile. In cracking clay soils such as Vertisol, it varies with water content (Bridge and Ross, 1984). In Vertisols, bulk density should be corrected for soil water content at the time of sampling, and bulk density values adjusted at field capacity moisture content assuming three dimensional matrix shrinkage.

Effective soil depth is a good indicator of plant available water capacity, subsoil salinity and other root growth constraints in the soil profile. It is not known whether trends can be discerned over relatively long periods (Walker and Reuter 1996, Doran and Parkin 1996). Surface crust retards seed germination and reduces aeration and water entry. It provides an indication of soil structure decline (Aggarwal *et al.,* 1994, Bridge 1997). However, it needs to be quantitatively measured or alternatively photographed over time and the extent of area quantified. Surface cover by either crop residues or vegetation protects soil surface from raindrop impact, enhances infiltration, reduces soil erosion and may decrease runoff (Freebairn and Wockner 1986). The extent of surface cover therefore provides an integrated indicator of soil physical management, organic matter input and the effects beyond farm gate. It can be measured by satellite imagery (currently expensive), and by combining with the terrain and digital elevation mapping, may provide an indicator of erosion hazard. However, correct timing of monitoring in relation to cropping and vegetation cycle and erosive rainfall periods is essential.

4.1.8.3. Biological indicators of soil quality

Among the biological soil quality indicators, soil microbial biomass and/or respiration, potentially mineralizable N, enzyme activity, fatty acid profile or microbial biodiversity, nematode communities and earthworm populations are quite predominant. Soil microbial biomass is a labile source and sink of nutrients. It affects nutrient availability as well as nutrient cycling and is a good indicator of potential microbial activity (Dalal and Mayer 1987, Myrold 1987) and capacity to degrade pesticides (Perucci and Scarponi 1994). Although useful as a research tool, its cumbersome measurement and variability with short-term environmental conditions makes it difficult as a routine soil quality indicator (Sparling 1997, Dalal 1998). Respiration measurements are also similarly affected. However, respiration rates can be measured in the field using portable CO_2 analyzers.

Easily oxidizable N and potentially mineralizable N are measured by alkaline-$KMnO_4$ method and aerobic or anaerobic incubation respectively. Anaerobic method is considered to be more effective and is recommended as routine procedure. Potentially mineralizable N measures soil N supplying capacity and is also a surrogate measure of microbial biomass and a labile fraction of soil organic matter (Rice *et al.* 1996). Soil enzyme activity is often closely related to soil organic matter, microbial activity and microbial biomass. It is sensitive to change in management practice and can readily be measured. Of numerous soil enzymes, dehydrogenase is a potential indicator of active soil microbial biomass. However, it is very sensitive to seasonal variability. Potentially useful indicators of soil quality could be beta-glucosidase, urease, amidase, phosphatase, and aryl-sulphatase and fluorescein diacetate hydrolyzing enzymes. Since enzyme activity is operationally defined, it requires strict protocol (Dick *et al.* 1996).

Soil fauna (soil meso and macro fauna), including nematode communities, affect soil structure, alter patterns of microbial activity and influence soil organic matter dynamics and nutrient cycling (Heal *et al.,* 1996), and are sensitive to soil disturbance and contamination. Of the soil invertebrates, earthworms and nematodes are the potential indicators of soil quality (Pankhurst 1994, Blair *et al.* 1996).

It has been understood that some of the soil indicators do not change immediately and take some time for getting influenced through management practices. Hence, for to be more objective in the approach, these indicators need to be monitored after a specific intervals only. The set of indicators used for assessing soil quality can vary from location to location depending on the kind of land or land use, soil function and the soil forming factors. The dimension of scale influence soil quality assessments in both space and time. The area of consideration can be as small as a point on the landscape, a research plot, or as large as a nation or the world. Time frames are important because of the effect of climate, soil moisture conditions, human actions, stage of plant growth, and other factors that give rise to temporal variability in indicator status.

4.1.9. Integration of quantitative indicators in to single value index-soil quality index

Although some indicators of soil quality may be sensitive to change, others may be more stable. In order to reach a valid conclusion, the quantitatively assessed indicators can be transformed to a single value soil quality index. These single value indices can be used to reliably predict the effects of farming systems and management practices on soil productivity, environmental quality, food safety and quality and human and animal health. A valid soil quality index would help interpret data from soil measurements and show whether management and land use are having the desired results for productivity, environmental protection and health (Granatstein and Bezdicek, 1992). Both quantitative and qualitative soil quality indices have been proposed. Qualitative measures of soil quality tend to be more subjective in their measurement, but can be assessed more easily and sometimes being more informative.

Karlen and Stott (1994) and Karlen *et al.* (1994a) developed a framework for quantifying soil quality using multi-objective analysis principles of systems engineering. They defined critical soil functions and potential chemical and physical indicators of those functions. For each indicator a scoring function and realistic baseline and threshold values are established. All indicators affecting a particular soil function are grouped together and assigned a relative weight based on importance. After scoring each indicator, the value is multiplied by the appropriate weight, and an overall soil quality rating is calculated by summing the weighted score for each soil function.

4.1.10. Soil quality assessment - Status in India

Since long, in India, assessing of soil quality was restricted to testing of soil for fertility status such as availability of nitrogen, phosphorus and potassium. Thereafter, the importance of some other essential nutrients such as sulphur, zinc, iron, manganese, copper, molybdenum and boron was also understood and these elements were also included in soil testing programmes. Monitoring of acidity and salinity using pH and EC values also became important. At present, in the country, there are about more than 600 soil testing laboratories mandated with the responsibility of doing routine soil testing for judicious fertilizer recommendation. Despite all these efforts, testing of soils seasonally or once in a year has not become routine practice by one or the other reason. Majority of the farmers, those who are financially sound apply fertilizers without giving due consideration to native soil fertility and nutrient requirement of the targeted crop or cropping system.

No doubt, soil fertility is one of the important aspects of soil chemical health, nevertheless, other two components viz., soil physical and biological health too assumes importance to determine the overall productivity of soil. The monitoring of soil physical parameters such as soil aggregate stability against water and wind erosion (soil structure), bulk density, aeration and porosity, infiltration and hydraulic conductivity, unfortunately, has not become the part of routine or even periodical soil testing programmes in India.

4.1.11. State of the art of research on soil quality across the world

In recent years, soil quality research has focused on the linkages among management practices and systems, observable soil characteristics, soil processes, and performance of soil functions (Lewandowski *et al.*, 1999). More research is required to choose the appropriate soil attributes among potentially many soil properties, (Nortcliff, 2002). FAO emphasized that it is of paramount importance to deeply look back into soil health of diversified rainfed ecology using some standard yardsticks and methodology. Larson and Pierce (1994) proposed three different functions associated with good soil quality. These included the ability of a soil to i) function as a medium for plant growth, ii) regulate and partition water flow through the environment and iii) serve as an environmental filter. To perform these functions, they stated that a high quality soil accepts, holds and releases nutrients and water, promotes and sustains root growth, maintains suitable soil biotic habitat, responds to management, and resists degradation. Doran *et al.* (1996) stated that soil quality indicators should be sensitive enough to detect effects of management practice, but should not be affected by short-term weather patterns. Soil quality indices and indicators should be selected according to the soil functions of interest and defined management goals for the system. Management goals are often individualistic, primarily focused on on-farm effects but can also be societal, including the broader environmental effects of farm management decisions such as soil erosion, agrochemical contamination of soil and water, or subsidy imbalance (Rapport *et al.*, 1997). Hussain *et al.,* (1999) suggested that sustainability of agricultural management system has become an issue of wide public concern and international debate. They have suggested soil quality assessment as a tool for evaluating sustainability of soil and crop management practices. While planning tillage systems, one should consider three soil functions: i) resist erosion (water relation), ii) provide plant nutrient (nutrient relation) and iii) provide favorable root environment (rooting relation). Felipe Bastida *et al.,* (2006) have suggested a microbiological degradation index as an effective method of evaluating soil degradation in semi arid tropics. In this microbiological degradation index (MDI) dehydrogenase activity, water-soluble carbohydrates (WSCh), urease activity, water-soluble carbon (WSC) and respiration emerged as important factors with greatest weight. Masto *et al.* (2007) used indicators affecting six soil functions namely i) soil's ability to accommodate water entry ii) to facilitate water movement and storage iii) to resist surface degradation iv) soil ability to resist biochemical degradation v) soil capacity to supply plant nutrient and vi) to sustain crop productivity.

4.1.12. Effect of management practices on soil quality

Several studies have emphasized the importance of management practices such as reduced tillage, residue recycling, conjunctive or integrated use of inorganic and organic sources of nutrients and adequate balanced fertilization in enhancing the yields on sustainable basis and improving the overall soil quality (Paustian *et al.,* 2000; Roldan *et al.,* 2003; Roldan *et al.,* 2007; Sharma *et al.,* 2004, 2005, 2008; Singh *et al.,* 2004**;** Smith and Elliott, 1990). In the traditional agriculture, tillage practices have been in use to ensure fine tilth, and better seedbed for good seed germination. Apart from hastening the process of decomposition of left over crop residues and stubbles, tillage accelerates the decomposition of soil aggregate-associated organic matter (Six *et al.,* 2000) and microbial functions (Young and Ritz, 2000). Over and above, tillage and crop residue management practices may significantly alter the composition, distribution and activities of the soil microbial community and enzymes (Paustian *et al.,* 1997).

Tillage, fertilization, crop rotation, water management, liming and cover crops are some of the soil management practices that can significantly affect soil quality. Tillage is used to incorporate residues, prepare a seed bed, control weeds, and incorporate lime, fertilizer and other chemicals and by doing so, will often enhance plant growth and thus improve soil quality. Negative effects associated with tillage include erosion caused by the physical downhill movement of soil (i.e. tillage erosion), exposure of the soil surface to wind and water erosion, and loss of soil OM through oxidation. To balance these factors, no-tillage or conservation tillage practices are being developed and recommended as management strategies to improve soil quality throughout the world (Karlen *et al*., 2004).

Fertilizer applications can have either positive or negative effects on soil quality. Identifying yield limiting nutrients and using fertilizers to correct the deficiencies often increases crop yield and organic inputs (above and below ground). However, repeated application of ammonical fertilizers and leaching of excess nitrate nitrogen can degrade soil quality through acidification. Crop rotations can be used to improve soil quality by altering the quantity and quality (ie C: N ratio and lignin content) of residue added to the soil, varying the soil space utilized for nutrient and water uptake by using crops with different rooting patterns, and providing cover to protect soil from erosion (Karlen *et al*., 2004).

Water management affects soil quality primarily through the effects on plant growth. In regions where precipitation is sufficient to support adapted crops, the primary soil quality concerns are to minimize runoff and leaching by achieving good infiltration and storage within the soil profile. If soil water levels are consistently high, plants must be adapted to the saturated conditions or drainage must be installed. Drainage generally improves aeration and allows the production of a wider range of crops, but can degrade soil quality by enhancing soil OM decomposition. In regions, requiring irrigation for crop production, irrigation water quality, irrigation scheduling, method of irrigation and drainage potential (for leaching of salts from the soil profile and prevention of water logging) are critical management concerns (Karlen *et al*., 2004).

4.1.12.1. Soil organic matter

Any management practices, which influence organic matter, can play an important role in influencing soil quality. It has been well established that organic matter (OM) is a key component in the creation and maintenance of high quality soil. Many soil properties are directly affected by the presence of organic matter. Indirectly, soil organic matter influences the quality of the air and water that interact with the soil. As water infiltrates the soil, the biological activity supported by soil OM transforms the substances contained in the water. The production and emission of green house gases from soil are largely controlled by how soil organic matter is managed. Soils with increased levels of OM require higher application rates of pesticides for effective pest control and pesticides may become more resistant to degradation (Loux, *et al*., 2002). The OM in soil can range from less than 1% in coarse textured or highly oxidized soils to nearly 100% in wetland bogs. In general, farm soils have concentrations of soil OM that generally range between 1 and 10%. The chemical composition of soil OM can vary depending on when and where soil is sampled but typically contains about 50% carbon, 40% oxygen, 5% hydrogen, 4% nitrogen and 1% sulphur. Organic matter contributes to the overall quality of a soil. Soil OM is a repository of nutrients (N, P, S and micronutrients) and during its turnover, contributes to fertility at times and in locations in the soil profile that are difficult to achieve with inorganic nutrient amendments. It increases the cation exchange capacity, particularly in coarse textured soils and increases the soils available water holding capacity (Hudson, 1994). In addition, soil OM enhances aggregation, which improves soil tilth, the infiltration of water and the exchange of gases between soil and atmosphere. It can have a positive effect on yield of crops (Dick and Gregorich, 2004).

Probably, tillage and erosion are the two greatest disturbance events that affect soil OM concentrations. Many studies have shown that a rapid decrease in OM concentrations takes place when native soils are brought under the plough. In general, the decline in soil OM occurs in two phases. An initial rapid decrease occurs in the first 10 – 20 years as the aggregates are broken down and the readily available OM is decomposed. Then a slower phase occurs as more recalcitrant OM is decomposed, along with any newly deposited materials. This phase can continue for many more years until a new equilibrium level is obtained. When a native ecosystem is converted into arable agriculture, losses of OM could be as high as (60-70%), however, the general range varies between 2 to 50% in the zone of cultivation (Lal *et al*., 1998). This loss of organic matter that occurs upon conversion of native ecosystems into arable agriculture is attributed primarily to four factors: i) the amount of OM returned to the soil in plant litter is often lower in agricultural systems than in native systems. This is because under agricultural production, a portion of organic material in the crop is harvested and removed from the system, ii) there is a change in plant species when a native system is converted into agricultural production. This change often results in a change in shoot and root OM deposition within the soil profile, iii) a change in the soil climatic conditions (temperature and moisture) and soil conditions (disruption of stable, protected OM by tillage) occurs under agricultural production, particularly cultivated systems, leading to greater mineralization of organic matter than under native uncultivated systems, iv) there is a redistribution and subsequent loss of soil, with preferential losses of the finer particles rich in labile OM, due to water, wind and tillage erosion processes. Management systems, which include intensive tillage with mechanical summer fallow in alternate years with little nutrient input affects soil OM levels by reducing C inputs into the soil and feature high levels of disturbance. Hence the practices that cause an increase in the level of soil OM are generally those that are also most sustainable (Dick and Gregorich, 2004).

In cultivated soils, organic matter is rapidly depleted from native levels toward a low equilibrium. Even though the native soil organic carbon depends on soil type, after many years of cultivation, it approaches approximately 0.5% less. Jones and Wild (1975) found that the annual loss of soil organic carbon under cultivation ranges from 5 to 10% and that after many years of cultivation, SOC is 25 to 45% of what is under natural vegetation. Fallowing is not an effective way to increase soil organic matter. Even small increases in organic matter content require repeated organic additions over many years. For example, assuming a soil organic carbon decomposition rate of 6 % yr^{-1}, build up of SOC from 0.3 to 0.4% would require approximately 15 t ha^{-1} of cereal straw and 31 t ha^{-1} of animal manure. These huge amounts of organic material are available only if fertilizer is used, or if organic material from a large area is concentrated in a small area (Carsky *et al*., 1998).

4.1.12.2. Effect of tillage on soil quality

Effect of tillage on soil quality has been reported by Hussian *et al*., (1999) in more elaborative manner. Tillage has been found to play a crucial role in influencing the various soil properties including organic C and POC fraction in soil. Change in frequency and intensity of tillage practices considerably alters the soil properties, distribution of nutrients, and soil organic matter in the soil profile. Hussain *et al* (1999) conducted 8 year study with the tillage treatments comprising of management treatments such as no- till (NT), chisel plow (CP), and moldboard plow (MP) in corn (*Zea mays* L.)-soybean (*Glycine max* (l.) Merrin) Oxyaquic Fragiudalf) soil in Southern Illinois. In the eighth year, soil pH, exchangeable Ca, and Bray P-1 were greater in NT than in CP and MP in the 0-to 5- cm soil depth. In the 0- to 5-cm soil depth, exchangeable K and Mg were greater with the CP than with the NT and MP. Soil pH and P were greater for CP than MP and NT in the 5-to 15-cm layer. In the 0- to 5-cm soil depth, NT, CP and MP had 38, 35, and 31% of their total C as particulate organic matter (POM), respectively. After 8 yr, CP and MP had less Total organic C than NT in the 0- to 5-cm depth. In the 0- to 5-cm depth, CP and MP had less POM C than NT.

The greater reduction of organic C in the POM fraction than in whole soil showed that POM was the most tillage- sensitive fraction of organic matter. After 8 yr of study, the water – stable aggregates in the 0-to 5-cm soil depth of MP and CP was reduced compared with NT. At the end of 8 yr, the NT maintained or improved nutrient retention and aggregate stability in the 0- to 5-cm layer compared with MP and CP. In many earlier studies also, similar observations have been emerged.

Several other reports have revealed that change in frequency and intensity of tillage practices alters soil properties, distribution of nutrients, and soil organic matter in the soil profile. These changes become stable with time and could affect availability of nutrients for plant growth, crop productivity. No tillage (NT) system on long-term basis accumulates nutrients in the soil surface, whereas moldboard plough (MP) distributes nutrients relatively uniformly through the tillage depth. Stratification of nutrients has been observed in two long – term tillage studies under NT, whereas, soil mixing promotes uniform distribution of nutrients in MP and CP (Karlen *et al*., 1991; Ismail *et al.,* 1994; Mackay *et al*., 1987). In contrast, Karlen *et al.,* (1994) and Franzluebbers and Hons (1996) observed differences in nutrients distribution due to tillage system. Soil pH decreased at the soil surface in no tillage system because of surface – applied N (Blevins et al., 1983).

Any change in organic C contents due to tillage can affect cation–exchange capacity (CEC) of soil. Due to higher organic C, no – till resulted in a significant increase in CEC in the 0- to 15-cm sandy clay loam layer compared with CP and MP after 28 yr of cultivation (Mahboubi *et al*., 1993). After 12 yr of a tillage study, Karlen *et al*., (1994) found no differences in CEC due to tillage system.

Organic matter plays an important role in nutrient availability and soil aggregate stability. Soil productivity decreases when soil organic matter (SOM) declines (Bauer and Black, 1994). High residue – producing crops in combination with NT increase SOM (Havlin *et al*., 1990), while SOM declines with low residues – producing crops like soybean in combination with mold board plough (Edwards *et al*., 1992). Crop residues have a residual effect on crop growth, organic C, and N availability (Christensen *et al.*, 1994: Maskina *et al*., 1993). Accumulation and distribution of organic C in soil is affected by different tillage practices and time after initiation of tillage. Ismail *et al*., (1994) observed a decrease in organic C in 0 to 30 cm silt loam layer during the first 5 yrs, no change in the next 5 years, and an increase in organic C in the last 10 years in both NT and MP in comparison with sod plots. Organic C was higher in NT than in MP. Hunt *et al*., (1996), Alvarez *et al*., (1995), Angers and Giroux (1996), and Karlen *et al*., (1994) found that under NT organic C increased compared with MP and CP in the top 5 cm of soils with a range of soil textures, including loamy sand, silt loam, and silty clay loam.

More water – stable aggregates (>250 µm) were found in a silt loam soil after continuous wheat (*Triticum aestivum* L.) as compared with a wheat – fallow rotation system because of continuous addition of residue (Monreal *et al*., 1995) . After 10 yr of no tillage system, continuous corn, Karlen *et al*., (1994), found that removal, maintenance, and doubling of crop residue resulted in 42, 46, and 60% wet aggregate stability, respectively.

Water–stable aggregates are divided into macro- and micro aggregates, and different organic matter fractions are responsible for the formation of these aggregates. Temporary and transient binding agents are thought to be for macro aggregation (> 250 µm) (Dormaar, 1983; Tisdall and Oades, 1982). Persistent binding agents are important in micro aggregation (<250µm) of soil (Tisdall and Oades, 1982).

Macro aggregates are more susceptible to physical disruption because of the labile nature of binding agents. The labile transient and temporary binding agents described by Tisdall and Oades (1982) were related to POM. Particulate organic matter is the slowly decomposable or stabilized fraction of organic matter, which is composed of root fragments in various stages of decomposition (Cambardella and Elliot, 1992). The POM was related to the slow fraction, which is physically protected and somewhat resistant to decomposition, with a turnover time of 20 to 40 yr (Patron et al., 1987).

After 20 yr, Cambardella and Elliot (1992) reported for a loam soil that organic C as POM was 39, 18, 19, and 25% in sod, bare fallow, stubble mulch, and NT, respectively. They suggested that NT reduced POM loss caused by tillage and aeration. They found that the higher C/N ratio in the POM fraction in NT was due to less decomposition of straw on the soil surface as compared with bare fallow. The C/N ratio of the mineral – associated fraction of organic matter was not significantly different because this fraction was in a more stabilized form.

Beare et al., (1994) found on a sandy clay loam soil that after 13 yr of continuous NT and MP with grain sorghum [*Sorghum bicolor* (L.) Moench] and winter rye (*Secale cereal* L.), 36% of total organic C was POM C in both treatments. No-till had 20% more total organic C and POM C than in mold board ploughed plots after 13 years. Organic C and POM C in sand – free aggregates at 0 to 5 cm in no tillage system were higher than in MP ploughed surface soil samples, however, no significant differences occurred in the 5 to 15 cm layer.

From the above review, it is understood that researchers world over have entered in much more depth of soil quality assessment studies namely effect of management practices on carbon pools (MBC, POC, $KMnO_4$ oxidizable C, C associated with different aggregate size fraction), enzyme activities (urease, dehydrogenase, aryl-sulphatase, phosphotase, monoesterase etc.) instead of merely sticking to evaluation of soil fertility and few other soil properties.

In India during early years, assessing of soil quality was limited to testing of soil for fertility status such as availability of nitrogen, phosphorus and potassium. Thereafter, the importance of some other essential nutrients such as sulphur, zinc, iron, manganese, copper, molybdenum and boron was also understood and these elements were also included in soil testing programmes. Monitoring of acidity and salinity using pH and EC values also became important. The monitoring of soil physical parameters such as soil aggregate stability against water and wind erosion (soil structure), bulk density, aeration and porosity, infiltration and hydraulic conductivity, unfortunately, has not become the part of routine or even periodical soil testing programmes in India.

4.1.13. Advanced soil quality indicators - Research status

4.1.13.1. Soil enzymes and soil health

Enzymes in soil exist in two locations: (i) those associated with viable cells (intracellular enzymes) or (ii) as extra cellular enzymes. The intra cellular enzymes play central role in the innumerable life processes of cells. Whereas, the extra cellular or abiotic enzymes are those outside the living cells (Skujins, 1976).

An inherent difficulty of studying soil enzymes is that only small amounts of the total enzymes found in the soil can be extracted from soils. Stronger extractants generally denature proteins such as enzymes by disrupting the stereo specific structure of enzymes that is necessary for bio-chemical reactions. Consequently, most of the investigations on soil enzymes are done by measuring their activity directly in the soil. This has a number of implications for interpreting and understanding the role of enzymes in soils. Despite limitations of research methodology for studying soil enzymes, their specificity and integrative nature provide a potential basis for considering enzyme activity as an indicator of certain functions in soils. Relating soil enzyme activity to plant productivity has produced mixed results. Early work showed no close relationship of enzyme activity to crop yields or soil nutrient status (Koepf, 1954; Drobnik, 1957; Galstyan, 1960; Haban, 1967). Conversely, the studies of Verstraete and Votes (1977) showed that the activity of selected soil enzymes (phosphates, invertase, β- glycosidase and urease) were positively correlated with crop yields and that these measurements were superior to measurement of microbial abundance in correlating with soil fertility or crop yield. In managed systems, other factors may confound or override the relationship between soil enzyme activity and plant productivity. This is likely to be true for ago ecosystems where external inputs of nutrients and water can greatly stimulate plant growth without a corresponding response by soil microorganisms. As per the reports of Yaroschvich (1996), manure – amended soil increased soil respiration and enzyme activity but inorganic fertilizer – amended soils resulted in decreased enzyme activity. Crop yields, however, were the same when adequate nutrients were supplied from either inorganic or organic sources. There is some evidence that the activity of certain soil enzymes is better related to plant productivity under native conditions and in highly disturbed landscapes (Pancholy and Rice, 1973 a, b; Pancholy *et al*., 1975; Kiss *et al*., 1993).

4.1.13.2. Influence of enzymes on other biological indicators of soil quality

Interrelationships between various microbial indicators and soil enzymes viz., dehydrogenase, protease, cellulase, phosphotase and urease have been established by many researchers (Laugesen, 1972; Laugesen and Mikkelsen, 1973; Nannipieri *et al.,* 1978; Tiwari *et al.,* 1989). In an earlier study, Franken Berger and Dick (1983) evaluated 11 enzymes in ten diverse soils for their potential relationships with microbial respiration, biomass, viable plate counts and other soil properties. They found that alkaline phosphotase, amidase and catalase activities influenced both microbial respiration and total biomass but not microbial plate counts in glucose –amended soils.

4.1.13.3. Soil organic matter, carbon pools and soil quality

4.1.13.4. Soil organic matter (SOM) and Particulate organic matter (POM)

The role of soil organic matter and carbon pools in influencing soil quality has been comprehensively dealt by Bales Dent and Mariotti (1996). Soil Organic matter is a key biological indicator of soil health (Swift and Woomer, 1993; Park and Cousins, 1995). It is a direct product of the combined biological activity of plants, microorganisms and animals plus the myriad of a biological factor. It is responsible for crucial aspects of soil function such as aeration and fertility

(Elliott and Coleman, 1988). Soil organic matter (SOM) can be seen as a mixture of bio-genic components that include invariable proportions and evolutionary stages of microorganisms and non-decomposed plant materials (1-10%). Depending on the turnover time in soil, SOM can be either active (fast recycling, corresponding mainly to carbohydrate, amino acid, and lipid fractions), or passive or refractory (humic fraction), remaining in the soil for centuries to millennia (40-60%). The research is ongoing on these pools to better define these pools analytically (Christensen, 1996; Elliott *et al*., 1996) and mathematically (Powlson *et al*., 1996).

The significance of SOM lies in that it correlates well with a number of important physical, chemical, and microbiological properties of soil. The SOM content of agricultural topsoil, for example, is usually in the range of 0.1-6%. From a qualitative point of view, SOM influences the physical and chemical properties of soil as well as the availability of nutrients for microbial and plant growth. It accumulates over a long periods of time and its distribution in any soil profile is the result of continuous reprocessing by microbes, recombination by chemical reactions, physical movement by soil animals, disturbances such as tree falls, and movement of the soil solution. Consequently, carbon cycling and its stabilization in soils are intimately associated with soil structure.

Particulate organic matter (POM) is one of the important fractions of soil organic matter (SOM) that has the potential to serve as an indirect measure of soil health. There are various research reports on the half-life of POM. A half life of ~10-20 years has been reported for SOM at Sidney, Nebraska, USA and it has been found as an important contributor to soil aggregation (Cambardella and Elliot, 1993). It has been understood that POM is found in soil and outside aggregates and its C/N ratio varied with tillage. As plant material is decomposed, part is used by microbes, and eventually becomes microbial derived soil; organic matter hypothetically isolated as an enriched labile fraction (ELF) (Cambardella and Elliott, 1994), and the other part, that which is not decomposed, becomes plant derived soil organic matter (POM) (Elliott *et al*., 1996). POM and ELF have been found to represent a significant part of the total SOM (about half in some soils) and have higher concentrations under reduced tillage. POM is considered as substantial contributor to total OM (40-50% in native grassland cultivated for many years).

Reports suggest that soil health may be indicated by the measurement of the POM fraction because the turnover time allows enough sensitivity to detect changes within a few years. POM dynamics are not large over the growing season, except perhaps in highly degraded soils, so the method is relatively insensitive to time of sampling. It may also integrate responses over a number of years. The studies of Elliot *et al* (unpublished) after analysis of data from 20 agricultural experiments in the Central US revealed that POM-N and POM-N / total N were the best indices for comparing management treatment effects. Normalizing POM-N to total N allows one to account for variations in organic matter content, which may be affected by texture, climate or other driving variables. Before such measures can be used confidently as indicators of soil health, they must be tested over a wide range of driving variables and treatments. POM changes in response to these factors could be used to calibrate the method for general use as an indicator.

Further, the role of POM fractions has also been emphasized by Wander (2004). According to him, the labile SOM can be assessed effectively by characterizing POM fractions. POM fractions estimated by measuring low-density (typically 1.4-2.2 g cm^{-3}) or coarse – size fractions (>53-100 μm) are strongly influenced by soil management (Christensen, 1992; Quiroga *et al*., 1996). Focus on POM, in lieu of other measures of labile SOM is warranted largely because this fraction typically has a higher proportional response to management than do other measures of labile SOM (Conteh *et al*., 1998: Alvarez and Alvarez, 2000 and Franzluebbers *et al.,* 2000; Carter, 2002).

The material captured in POM fractions is composed primarily of plant – derived remains with recognizable cell structure and typically includes fungal spores, hyphae, and charcoal (Spycher *et al*., 1983; Molloy and Speir, 1977; Waters and Oades, 1991; Gregorich and Ellert, 1995). The proportion of charcoal is related to the site's history of burning (Elliott *et al*., 1991) and geomorphology (Di-Giovanni *et al*., 1999). Collectively, the size of the POM fractions, its relatively distinct nature, and its sensitivity to management, including inputs, support statistical resolution of differences between soils, this rather than purity or kinetic fidelity, explains the popularity of POM fractions as indices of labile SOM.

The value of POM as an indicator of early trends in SOM status in managed soils is well recognized by various workers (Bremer *et al*., 1994; Wander *et al*., 1994; Gregorich and Carter, 1997; Yakovchenko *et al*., 1998; Carter 2002). These researchers have suggested taking enough care to control timing, intensity, and pattern of sampling. Because POM contents, which are quite sensitive to plant inputs and soil mixing, can vary seasonally (Spycher, 1983; Wander and Traina, 1996b; Wilson et al., 2001), spatially (Burke *et al*., 1999; Bird *et al.,* 2001), according to handling (Yang and Wander, 1999), and with soil depth (Guggenberger *et al*., 1994; Wander *et al*., 1998; Aoyama et al., 1999). Management's influence on POM fractions appears to interact with texture in various ways.

Some works have found that sensitivity to management (Carter *et al*., 1998; Needelman *et al.,* 1999) and the proportion of SOM in POM (Liang *et al*., 2003) increases as sand content increases. According to Hook and Burke (2000), POM is especially important to N retention and availability in sandy soils, because the proportion of total N in POM is higher than in finer-texture soils. In coarser textured soils, POM contents decline with clay contents, if other factors do not limit decay. The inability to conserve POM can limit a sandy soil's ability to respond to management. Malhi *et al*., (2003b) attributed the failure of N fertilization to increase POM (cited in Noyborg *et al*., 1999) to its being too sandy, because similar N amendment of a loamy site had increased POM contents.

Besides textural constituents, soil background, or history of use also influences the sensitivity of POM fractions to management. Differences in outcomes reflect how close to or far from equilibrium or saturation an individual soil is when subject to new management and whether the regime or condition aggrades or degrades labile SOM.

Based on a study conducted in cotton production on a Vertisol, Conteh *et al.,* (1998) reported that the amount of POM obtained after 3 years in stubble incorporated soil was almost double than that obtained from a soil in which stubble was burnt. This suggests that both management and soil status were conductive to POM, and, presumably, gains in SOM. In contrast, Franzluebbers and Arshad, 1996a, found little to no effect of conservation tillage practices on SOM accretion in POM in northern temperate soils, where cold climate minimized decay. In that instance, POM trends indicate that alternative management was not sufficient to prompt SOM aggradation. Carter *et al*., (2003) suggested that although POM fractions reach saturation later organic matter affiliated with mineral surfaces, SOM –saturated soils fail to accumulate POM under practices that would typically be considered aggrading. It is important to remember that SOM equilibrium levels are dynamic, varying in individual soils with the pattern, intensity inputs, and disturbance. The quality and character of organic residues added to any soil, including one in which soils are considered to be SOM saturated or at equilibrium under present management

4.1.13.5. Microbial biomass carbon and soil quality

Among the labile pools of carbon, the microbial biomass carbon (MBC) has been considered as a sensitive indicator of changes in soil processes because it has a much faster rate of turnover than the total soil organic matter (Jenkinson and Ladd, 1981; Paul, 1984). Several authors have suggested these trends in the microbial biomass contents (Powlson and Jenkson, 1981; Powlson *et al*., 1987; Sparling, 1992). This is consistent with the approach of Larson and Pierce (1994) who suggest that the rates of change in soil parameters, rather than the absolute values, can provide an assessment of longer term soil quality and health.

There are numerous examples of organic matter and microbial biomass decline under agricultural or land disturbance, indicating exploitation of the organic resource and the modifying influences of differing tillage systems, fertilizers and crop rotation (Carter and Rennie, 1982: Dalal and Mayer, 1987: Granatstein *et al*., 1987; Srivastava and Singh, 1989; Luizao *et al*., 1992; Sparling *et al.,* 1992; Weigand *et al.,* 1995). Relative to some reference site, the land management techniques that have least impact on microbial biomass and organic matter can be identified. Such studies generally assume that those land management methods causing greater rates of decline in organic matter will become less sustainable in the longer term because of the deteriorating physical, chemical and biological fertility of the soil. However it is clear that change in the microbial fraction is not always greater than that in the total C content, and can even show conflicting trends (e.g. the Tammin and Judge Ford soils).

Microbial biomass contents of degraded soils can provide a useful index to monitor soil restoration techniques. A non-degraded example of the soil provides a target value for the microbial biomass content, and the soil being restored can be monitored over time to provide an index of recovery. Microbial indices have been used to monitor the recovery of soil after topsoil stripping and lignite mining in New Zealand (Ross *et al*., 1984, 1992), in Germany (Insam and Domsch, 1988) and to follow changes in stockpiled soils (Williamson and Johnson, 1994).

Some authors (Hart *et al*., 1986: Williams and Sparling, 1988; Insam *et al*., 1991: Srivastava and Singh, 1991) have suggested a strong link between soil microbial biomass, soil fertility and soil health. A positive relationship between the microbial biomass content of soils and the amount of potentially available N as determined by anaerobic incubation or other tests has been shown several times (Hart *et al*., 1986: Myrold, 1987: Williams and Sparling, 1988: Stockdale and Rees, 1994). In contrast, a higher microbial biomass did not necessarily relate to greater soil, or plant yield (Sorn-srivichai *et al*., 1988). More biomass C and N was found under wheat with no fertilizer than under continuous wheat receiving N fertilizer (Biederbeck *et al*., 1984). Soil respiration was greater from less productive than more productive soils (Dinwoodie and Juma, 1998). Tate *et al*., (1991) found more organic matter and a greater microbial biomass C on a low fertility pasture site compared to a high fertility site. Organic matter and microbial biomass in an uncleared forest soil of very low fertility were similar to those under a productive pasture fertilized with lime and super phosphate for some 30 years (Sparling *et al*., 1994b).

There are several possible reasons for these trends. Biederbeck *et al*., (1984) suggested that a larger but less active biomass was present in the poorly fertilized system compared to a low fertility soil. Crops grown on soil with greater quantities of available nutrients may need less extensive root systems, less below – ground plant biomass and consequently a decreased microbial biomass, while still improving crop yield (Ladda *et al.,* 1994). High levels of inorganic nutrients and lower pH on fertilized plots may interface with biochemical assays to estimate microbial biomass (Widmer *et al.,* 1989: Amato and Ladd, 1994).

4.1.13.6. Carbon dioxide emissions, soil organic matter and soil quality

It is well-established fact that CO_2 fluxes from soil and organic matter on soil surface are major components of the terrestrial C cycle. There is no doubt that organic matter content of agricultural soils is highly correlated with their potential productivity, tilth and fertility. Organic matter despite being low in semi-arid dry soils, its effect on soil properties is of major significance even at low concentration. Organic matter is the major substance helping in soil aggregation and structural stability. Stable and good structures help in improving air and water relationships for root growth and also protect the soil from wind and water erosion. Some part of soil organic matter causes the gradual darkening of the soils, which increases their capacity to absorb heat and to warm rapidly during winter (Smith and Elliott, 1990).

Soil organic matter is heterogeneous mixture of living dead, decomposing organic and inorganic compounds. It is derived from plant, animal and microbial tissues and contains various amounts of C, H, O, N, P and traces of other elements. It has been reported that about 15% of SOM constitutes polysaccharides, polypeptides, phenols and other simple organic compounds (Alexander, 1977). The remaining SOM is considered as humic material. This humic material is characterized by dark amorphous colloidal substance derived from chemical, physical and biological transformation of plant and animal material. It is understood that equilibrium level of organic matter depends upon various interacting factors including precipitation, temperature, soil type, tillage, cropping systems, the type and quantity of crop residues returned to the soil and the method of residue application whether surface applied or ploughed in. It has been widely studied that reductions in soil organic matter over time in agricultural soils are largely due to tillage, no or less recycling back to the soil, and soil erosion. When frequent inversion tillage is done and residues are mixed in soil it decomposed fast. Further, tillage breaks down the micro-aggregates and pumps more oxygen in soil, which aggravates the oxidation of entrapped organic matter in soil. The losses in SOM due to tillage in semi- arid regions have been reported to the extent of 20-50 %. Loss of SOM in soil occurs as CO_2 emission. Measurement of soil respiration or CO_2 soil flux when soils are without crop can give some quantitative information on the effect of tillage, residue and fertilizer application and other management factors on SOM loss.

Soil respiration is the total heterotroph metabolism plus a variable component of root respiration, but is a useful indicator of soil activity. Measurement CO_2 flux from soil helps in studying C storage and C budget and build up or depletion in Soil Organic C (SOC) over a period of time The CO_2 emission from soil is mostly influenced by soil temperature, soil moisture microbial activity, tillage, residue application, type of residues, soil moisture and root respiration. If the emissions are measured in soil without crop, then the contribution of root respiration can be minimized.

4.1.13.7. Soil nitrogen pools

Nitrogen is the most common limiting nutrient in crop production and its status in the soil has been proposed as an index of soil biological degradation (Gonzalez-Prieto, 1997). One universally important attribute of soil quality is the availability of plant nutrients, whether these are derived from residues of previous nutrient dressings, atmospheric deposition or the soil parent material, or are provided directly to the crop by mineral fertilizers and animal manures. An adequate and balanced availability of a wide range of macro- and micronutrients is required to optimize plant growth, but in most developed agroecosystems, the immediate limitation to productivity is the availability of mineral nitrogen. Nitrogen is a major element also in terms of the environmental impacts of agricultural activity, and nitrogen containing compounds of biosynthesis (amino acids and proteins) are crucial for the nutritive value of plant products and thus for animal and human health. Developing a sustainable nitrogen management policy is a particular challenge in maintaining soil quality. Agriculturally, soils contain a large pool of organically bound nitrogen. The pools of nitrogen that dominate the short-term nitrogen turnover are the decomposer biomass and labile OM pools. These pools of nitrogen are relatively dynamic and respond more readily to inputs of plant residues and animal manure, and to soil disturbances., eg by tillage (Christensen, 2004).

Due to its chemical nature and the large microbial potential in soil, nitrogen can occur in forms with widely different characteristics in terms of availability to plants and susceptibility to loss to the environment. In contrast to other plant nutrients, nitrogen can be considered a renewable resource in crop production since lost nitrogen can be replaced through biological or industrial fixation of atmospheric N_2. Loss of nitrate from the soil by leaching contributes to the eutrophication of fresh water bodies and coastal areas. Nitrification and denitrification cause gaseous losses of nitrous oxide (N_2O), which is a most potent agent in global warming. Volatalization of ammonia may deteriorate nutrient –restrained natural ecosystems and cause acidification when returned from the atmosphere through wet or dry deposition. While, nitrate is mobile in water and subject to denitrification, nitrogen in ammonium form is retained in the soil through adsorption to soil colloids or fixation in clay minerals. By far, the largest fraction of organically bound nitrogen will be retained in the soil, but under some circumstances, losses of organic nitrogen dissolved by percolating water may be significant (Murphy *et al*., 2000) (Christensen, 2004). If lost nitrogen is not replaced by management, the soil pool of mineralizable and thus potentially plant available nitrogen will gradually be depleted. This will reduce not only the productivity of the agroecosystem, but will also affect the nutritive quality of the products. Although the protein components of diets may be derived from leguminous crops with symbiotic N_2- fixing capabilities, a balanced diet requires sources of dietary energy from crops relying on mineral nitrogen. The accumulation of organic nitrogen in the soil is a characteristic feature of terrestrial ecosystems, and understanding the regulation of soil nitrogen turnover in natural ecosystems can enable us to develop management that better sustains soil quality (Christensen, 2004).

The disturbance of soil structure brought about by tillage influences nitrogen turnover by modifying aeration and soil moisture, which in turn affect the activity of plant roots and soil organisms. Tillage may disrupt macro-aggregates, whereby particulate OM protected within aggregates is released an exposed to decomposition. Depending on the nature of the newly exposed substrates, tillage may result in a temporary increase in nitrogen net mineralization or net immobilization (Christensen, 2004).

Soil nitrogen assumes great importance among all the essential nutrients in the soil, for crop productivity is largely determined by it and hence soil fertility and soil nitrogen had almost become synonymous to each other during the past. The need for reliable prediction of N availability in soils has increased due to economic and environmental incentives to use available N more efficiently in crop production and minimize losses of N from cropland to the environment. These incentives have stimulated continued research on N availability indices in several areas including: (i) development of new chemical indices; (ii) modification and improvement of aerobic incubation procedures to provide more accurate assessments of N availability and facilitate an improved understanding of the characteristics of mineralizable N in soils; and (iii) development and evaluation of field tests for N availability.

Soils gain nitrogen from the atmosphere through various naturally occurring processes viz. i) biological fixation of nitrogen, which includes the fixation by a) blue green algae, b) free living bacteria and, c) bacteria living with symbiosis with leguminous as well as non-leguminous plants, ii) non-biological fixation of nitrogen, iii) atmospheric precipitation, and iv) sorption of combined nitrogen from atmosphere. It has been understood that management practices play an important role in influencing the quantum of nitrogen in different pools and transformation of N from one pool to another and consequently impact nitrogen release and availability to growing crops. Thus, the depletion or build up of N in these pools clearly manifests soil quality. The total nitrogen content of soils ranges from less than 0.02 % in subsoil to 2.5 % in peats. The nitrogen present in soil can generally be classified as inorganic or organic. About 95% or more of the nitrogen in surface soils usually occurs in organic forms.

4.1.13.8. Inorganic N pools

Most soils contain inorganic nitrogen (N) in the form of ammonium (NH_4^+) and nitrate (NO_3-). Nitrate (NO_2-) also may be present, but the amount is usually too small to warrant its determination, except in cases where NH_4+ or NH_4+ forming fertilizers are applied to neutral or alkaline soils. Several other forms of inorganic N have been proposed as intermediates during microbial transformations of N in soils, including hydroxylamine (NH_2OH), hyponitrous acid ($H_2N_2O_2$), and nitramide (NH_2NO_2), but these compounds are thermodynamically unstable and have not been detected in soil.

The inorganic combined N in soils is predominantly NH_4^+ and NO_3 with the exception of neutral to alkaline soils receiving NH_4^+ or NH_4^+ producing fertilizers. NO_2^- is seldom present in detectable amounts, and usually its determination is unwarranted. Until the 1950s, inorganic N was believed to account for <2% of total soil N, on the assumption that NH_4^+ and NO_3^- are completely recovered by extracting soil with a neutral salt solution. The validity of this assumption was challenged by the past 30 year findings that some soils contain NH_4^+ in a form that is not extracted by exchange with other cations (e.g Rodrigues, 1954; Dhariwal and Stevenson, 1958; Stevenson and Dhariwal, 1959; Bremmer and Harada, 1959: Bremmer, 1959: Walsh and Murdock, 1960: Schachtschabel, 1960, 1961; Young, 1962) and by estimates that the proportion of soil N in this form can exceed 50% for some subsurface soils (Stevenson and Dhariwal, 1959; Young, 1962). In such cases, NH_4^+ is said to be fixed, and fixed NH_4^+ has subsequently been defined as the NH_4^+ in soil that cannot be replaced by a neutral potassium salt solution (SSSA, 1987), such as 1 or 2 M KCl or 0.5 M K_2SO_4, in contrast to exchangeable NH_4^+, which is extractable at room temperature with such a solution. Existing information indicates that fixed NH_4^+ occurs largely, if not entirely, between the layers of 2:1- type clay minerals, particularly vermiculite and illite (hydrous mica), and that fixation results from entrapment of NH_4^+ in ditrigonal voids in the exposed surfaces upon contraction of the clay lattice (Nommik and Vahtras, 1982). The term, non-exchangeable NH_4^+, has been used by Bremner (1965) and Keeney and Nelson (1982) as a more precise alternative to fixed NH_4^+, Several other forms of inorganic nitrogen, including hydroxylamine, hyponitrous acid, and imido-nitric acid (nitramide) which were assumed as intermediates in microbial transformations of N have not been detected in soils (Bremmer, 1965).

The determination of exchangeable NH_4^+, NO_3^-, and NO_2^- in field soils is complicated considerably by extensive spatial variability (Biggar, 1978), and special sampling techniques based on knowledge of this variability may be required (Van Meirvenne and Hofman, 1989). A further complication is that these forms of N are subject to microbial transformations, which can lead to rapid changes in the inorganic-N content of a soil or soil sample. To minimize such changes, analyses of inorganic N should be carried out immediately after sampling. In most cases, however, some delay is unavoidable because of the need to transport the sample to the laboratory and sieve it before the analysis can be performed, and in some cases, the sample may be stored for later analysis. Various chemicals have been employed to minimize microbial growth during transport or storage of soil samples for inorganic-N analysis (e.g., volatile organic compounds, salts of heavy metals), but such treatments have given erratic results (Storrier, 1966; Robinson, 1967), and they can interfere with analyses for inorganic N (Bremner, 1965).

4.1.13.9. Organic nitrogen pools

The organic forms of soil nitrogen occur as consolidated amino acids or proteins, free amino acids, amino sugars and other complex, generally unidentified compounds. The latter group is believed to include materials that result from i) the reaction of ammonium with lignin, ii) polymerization of quinones and nitrogen compounds, and iii) the condensation of sugar and amines. The proportion of total soil nitrogen usually accounted for in these various fractions is as follows; bound amino acids 20 to 40 %, amino sugars such as the hexosamine 5 to 10 %, and purine and pyramidine derivatives 1 % or less. Very little is known about the chemical nature of the 50 % or so of the organic nitrogen not found in these fractions.

Proteins are commonly found in combination with clays, lignin and perhaps other materials and this has been suggested as one of the reasons for their resistance to decomposition. The existence of these proteins is deduced from the presence of amino acids found in acid soil hydrolyzates. It is assumed that because proteins are formed by a combination of amino acids, the presence of these amino acids in the hydrolyzates is proof of the existence of proteins in soils. Analytical techniques are now available, making it possible to isolate free amino acids from soils, which are not in peptide linkages or in combinations with high molecular-weight organic polymers, clays or lignin. The suitability of these substrates for biological oxidation would imply that they would not build up in large quantities in soils. The ease with which they are decomposed also suggests that they may be a more important source of NH_4^+, the substrates for the nitrifying bacteria, than the nitrogen in the more insoluble consolidated amino acids, the amino sugars, and the lignin and humic complexes. Relative to other forms, the quantities of free amino acids in soils are low (Tisdale *et al*., 1985).

The amino acids associated with proteins are alpha amino acids. However, soils also contain non-protein amino acids (Stevenson, 1982). Both "free" amino acids (Sowden and Ivarson, 1966) and "free" peptides (Paul and Tu, 1965) are possibly present in soils but are difficult to evaluate. Despite variations in methods of analysis and in the nature of soils, the distributions of amino acids in soils is fairly similar and up to 30 amino acids have been reported so far (Biswas and Das, 1957; Bremner, 1967; Kowalenko, 1978).

As far as amino sugars are concerned, they have not yet been detected in the free state but they exists as structural component of a large group of substances, the muco-polysaccharides; some of these materials may exist as Chitin, a polymer of N- acetylglucosamine (Stevenson, 1957; Bremner, 1958; Singh and Singh, 1960). Sowden *et al*. (1977) summarized the available information and observed that amino sugar-N content is high in tropical and subtropical soils. This may be due to high degree of decomposition at elevated temperatures with selective stabilization of amino sugars. Gallali *et al* (1975) obtained a direct relationship between the percentage N as amino sugar and Ca^{+2} content of soils; higher percentage N as amino sugar –N was observed with $Ca+^{2}$ saturated soils. It has also been observed that application of urea and herbicides to soil increases amino sugar –N content (Namdeo and Dube, 1973). Hydrolyzable unidentified N (HUN) in part, may occur as non- alpha- amino acid of arginine, trytophan, proline and lysine: and it may also be present as nucleic acid bases. Acid insoluble – N occurs mostly as a structural constituent of humic acids. However, the possibility of a considerable portion of this being an artefact, formed during acid hydrolysis through condensation of amino acids with reducing sugars, cannot be excluded.

4.1.13.10. Chemistry of nitrogen pools in soil

Mukherjee and Kunal Ghosh (1984) have earlier given a comprehensive account of chemistry of N fractions in soil. They have brought out that, most of the N in soils is present in organic combination, while the remainder, which usually is less than 5 % of the total N, is mainly fixed ammonia together with some nitrate and nitrite. Contribution of lattice-bound or fixed ammonium, generally increases down the soil profile. According to Stevenson (1982), the surface horizon of most cultivated soils has an N content ranging from 0.06 and 0.30%.

Most studies on the forms of organic N in soils are based on the use of hot mineral acids (or bases) to liberate nitrogenous constituents from organic colloids and clay minerals. In a typical procedure, the soil is refluxed with 3 or 6M hydrochloric acid (HCl) for 24 hours, after which the N is separated into several discrete fractions. Identifiable organic N compounds are the amino acids and amino sugars. The N remaining in the soil residue is usually referred to as acid-insoluble N; that recovered by distillation with magnesium oxide (MgO) is ammonia-N (NH_3-N). The nitrogen not accounted for in the above forms is referred to as the HUN fraction (hydrolyzable unknown N). In addition to amino acids and amino sugars, soils contain trace quantities of nucleic acids and other known nitrogenous biochemicals. However, specialized techniques are required for their separation and identification. Only one-third to one-half of the organic N in soils can be accounted for in known compounds.

Hence, the various fractions of N are as follows: i) NH_3-N: the N that is in the form of NH_3 and recovered from the hydrolyzate by steam distillation with MgO (whose contribution ranges from 20 to 35 %), ii) "amino acid-N (usual range 30 to 45 %), iii) amino sugar-N (range from 5 to 10 %), iv) hydrolyzable unknown N (HUN) which is about 10 to 20 % of hydrolyzable-N that cannot be accounted for by the above three groups, (v) and finally the acid insoluble-N: the N that is not solubilized by acid hydrolysis, whose contribution ranges from 20-35 %. Apart from these five important classes, small amounts of N may be contributed by a) nucleic acid bases like purines and pyramidines, whose contributions may be as high as 7.4 % total soil N (Cortez and Schnitzer, 1979), b) phospholipids like glycerophosphates; c) amines like choline, ethanolamine, histamine, urea, etc., whose formation is favoured under anaerobic or water logged conditions and quite few of them responsible for health hazards; d) N containing B- vitamins like biotin, thiamine, B-12 nicotinic acid and pantothenic acid, which are of special interest, since they act as growth promoters, and e) pesticides containing S-N in their structural moiety such as triazines, phenylcarbamates, substituted urease, etc. The variations in contribution of these organic and inorganic N fractions towards total N have been reported earlier by several researchers (Bremner, 1967; Subba Rao, 1979; Sharma *et al*., 1992; Mulvaney *et al.,* 2001).

4.1.13.11. Effect of management practices on nitrogen pools

There are several reports on the influence of management practices on nitrogen pools. Studies on the influence of fertilizers and manures on various nitrogen pools were initiated as early as 50's and various reports emerged. While studying the distribution of organic N fractions of the arid region under rainfed and saline water use conditions, Aggarwal *et al.* (1977), revealed that amino acid N and unidentified forms of N were the major fractions of the total hydrolyzable N under both conditions. Puranik *et al.* (1978) worked in Vertisol with continuous use of manure and fertilizers for 8 years and reported that insoluble humin-N contributed greatly to total N of the soil. The amino acid N was the second most important organic-N fraction and it was higher in FYM than in NPK. The contribution of this fraction to total nitrogen was 14.2 percent in control and 22.2 per cent in case of green manuring. They also pointed that large proportion of these fractions may be because of their resistance to decomposition. Subbiah and Sachadev (1981) in a ^{15}N study observed that major part of the added nitrogen accumulated in amino acid N and unidentified fractions of soil hydrolyzate. Stewart *et al.* (1963b) found that changes in amino acid N were closely related to inverse change in inorganic N of the soil. In addition to it, he found that 75 per cent of the nitrogen taken up by successive croppings of beet, barely and corn were derived from amino acid N. Keeney and Bremner (1966) noticed that cultivation led to a marked decrease in all forms of N, but very little change was observed in non-exchangeable NH_4^+, hexosamine and hydrolyzed NH_4^+, while marked decrease was observed in case of amino acid N, total hydrolyzable and unidentified nitrogen.

In an another study to see the equilibrium relationship between the inorganic and organic N fractions as affected by application of bioslurry and fertilizer N in a maize-mustard sequence, Sharma *et al.,* (1992) observed that 75.7% of total soil N was in the hydrolyzable N fraction. Among the hydrolyzable fractions, amino acid N, unidentified N and hydrolyzable NH4+ constituted 25.8, 25.7 and 18.6 % o f the total N respectively. Ammonium fixed in clay lattice constituted 19.1% of the total N. Application of bioslurry @ 13.3 t ha^{-1} under N-unfertilized conditions increased NO_3-N, fixed NH_4^+, amino acid N, hexosamine N and hydrolyzable NH_4^+. The magnitude of increase in total hydrolyzable and inorganic N fractions was 31.4 and 15.2 % respectively. Growing crops decreased N in the inorganic fractions. Transformation reaction of organic N to inorganic N was evident after second crop in the sequence. Fertilizer N application encouraged build-up of N in organic fractions, particularly in amino acid, hydrolyzable NH_4^+ and unidentified N fractions. Mulvaney *et al.* (2001) reported that the soil amino sugar fraction implicate as a key factor affecting the responsiveness of corn to N fertilization.

Reddy *et al.* (2003) reported that continuous application of 100 % NPK (+S), 150 % NPK (+S), and 100 % NPK (+S) + FYM for a period of 30 years in an Eutrochrept, led to a marked increase in organic C, total N, hydrolyzable N (viz., amino acid N, hydrolyzable NH_4-N, hexose amine N, and unidentified hydrolyzable N), and non-hydrolyzable N as compared to an adjacent fallow. The contents of the various organic N fractions were largest in surface soil and thereafter decreased with the depth. Continuous cropping without fertilization resulted in a depletion of total hydrolyzable N in control over fallow by 27.2 % (0-15 cm), 19.6 % (15-30 cm), and 4.7 % (30-45 cm). The incorporation of FYM with 100 %NPK (+S) resulted in greater contents of soil mineralizable N as compared to 100 %NPK (+S) (0-15, 15-30 cm). The proportion of hydrolyzable N (57-76 % of N_t) decreased and that of non-hydrolyzable N (22-40 % of N_t) increased with depth. The proportion of amino acid N (19-26 % of N_t), hexose amine N (2.1-3.5 % of N_t) and unidentified hydrolyzable N (17-27 % of N_t) decreased with depth. The best correlation to mineralizable N was found for amino acid N and the least significant correlation for non-hydrolyzable N.

4.1.14. Research Needs - Importance of study

Having reviewed the extent of the problem of land degradation and soil quality deterioration and the work done in India and abroad, it was understood that there exists a wider gap in research and development in the field of soil quality its assessment, restoration and maintenance systematically. To begin with, rainfed agroecology was considered more appropriate for such study as these soils are more prone to natural resource degradation and soil quality deterioration. In rainfed agro-ecosystem, various soil-nutrient management practices such as tillage, varying levels of manuring and fertiliser application, conjunctive use of organic and inorganic sources of nutrients, application of herbicides, different crop rotations (mono-crops, intercropping with legumes etc.,) are being experimented for last many years at experimental stations of All India Coordinated Research Project for Dryland Agriculture (AICRPDA). Besides these, farmers are also following different level of management to manage their farms. Some of these practices are quite beneficial and aggradative in nature, whereas, others are degradative. Because of degrading nature of some of the practices, soil quality has deteriorated considerably and response to the inputs such as fertilizer, water and other management levels has gone down. Poor soil quality associated with moisture scarcity resulted in stagnated low yields. Suitable soil quality restoration management practices and their periodical assessment are must to avert some of these undesirable changes and to improve the productivity of these rainfed soils on sustainable basis. Some of the practices which can help in restoration and improvement of soil quality on long-term basis could be appropriate conservation tillage, residue recycling, surface residue management, balanced nutrition, conjunctive use of organic and inorganic sources of nutrients, etc. Keeping in view the above studies were conducted with the following specific objectives during the period 2005 to 2009.

Objective 1: To evaluate the long term influence of existing selected soil and nutrient management practices on soil quality parameters, to identify the key indicators and to compute the soil quality indices under different cropping systems in rainfed areas across the country.

Objective 2: To evaluate the low-cost integrated nutrient management (INM) treatments (comprising of farm based organics) under conventional and reduced tillage in sorghum-mung bean strip cropping system in terms of sustainability of crop yields and long term effects on soil quality in Alfisol

Objective 3: To study the response of sorghum-cowpea system to graded level of surface residue application under minimum tillage in Alfisol and effects on carbon storage.

Objective 4: To study the influence of conjunctive use of residues and graded levels of N on crop yields and predominant N pools under sorghum-castor system.

4.2) Salient findings of the studies undertaken under each objective:

4.2.1. Objective 1: To evaluate the long term influence of existing selected soil and nutrient management practices on soil quality parameters, to identify the key indicators and to compute the soil quality indices under different cropping systems in rainfed areas across the country.

In all, seven centres of All India Coordinated Research Project for Dryland Agriculture viz., Parbhani (Maharashtra), Agra (Uttar Pradesh), Hissar (Haryana), Sardar Krishinagar (Dantiwada), Hoshiarpur (Punjab), Arjia (Rajasthan) and Rakhdhiansar (J & K) were selected for the study (Table 4). At each centre, longer duration experiments on soil and nutrient management practices comprising of tillage, fertilizer, residue application, green manuring, biofertilizers, and herbicides under different crops and cropping system etc., were adopted for assessing and monitoring the changes in physical, chemical and biological soil quality parameters. These parameters were successfully monitored.

Table 4: Description about the dryland centres adopted for the study during the five-year programme

SNo.	Targeted and studied Ecosystems	Climate	Soil type (Soil Order)	Locations
1	Rabi sorghum based production system	Semi arid	Vertisols	Parbhani (Maharashtra)
2	Pearl millet based production system	Semi arid	Aridisols	Sardar Krishinagar (Gujarat)
3		Arid	Entisols	Agra (Uttar Pradesh)
4		Arid	Aridisols	Hissar
5	Maize based production system	Dry sub humid	Inceptisols	Hoshiarpur (Punjab)
6		Dry sub humid	Inceptisols	Arjia (Rajasthan)
7		Dry sub humid	Inceptisols	Rakh Dhiansar (Jammu and Kashmir)
8	Sorghum-Mung bean based system	Semi arid	Alfisols	Hyderabad

4.2.1.1. Collection of soil samples from different locations under predominant management practices

Soil samples from different locations representing different production systems were collected for measuring soil quality indicators. The detailed description of the locations and management practices from where the samples have been collected is presented in Table 5.

Table 5: Details of the centres and experiment from where the soil samples were collected for the soil quality assessment studies

Sno	Brief description of the experiment	Predominant managememt component	Date of initiation of the experiment (Time period)	Duration completed at the time of sampling
A) Rabi sorghum based production system				
Name of the Centre: Pharbhani				
Climatic zone: Tropical hot moist sub-humid climate				
Soil type: Vertisols				
1	Organic farming comprising of INM treatments and legume based cropping systems	INM	1994-2008	12 years
	a) Sorghum + pigeon pea (4:2)			
	b) Soybean + pigeon pea (4:2)			
	c) Cotton + black gram (1:1) and			
	d) Mung bean + rabi sorghum			
B) Pearl millet based production system				
Name of the Centre: Sardar Krishi Nagar, Dantiwada, Gujarat				
Climatic zone: Hot arid				
Soil type: Aridisols (Deep loamy desert soils (Inclusion of saline phase))				
1	Long term manurial trial	INM	1989-2006	17 years
Name of the Centre: Agra, Uttar Pradesh				
Climatic zone: Hot semi-arid				
Soil type: Entisols (Deep loamy alluvium –derived soils, with occassional saline and sodic phases)				
1	Long term experiment in major production system	INM	2002-LT	4 years
2	Tillage and nutrient management for resource conservation and	Tillage	2000- LT	5 years

Sno	Brief description of the experiment	Predominant managememt component	Date of initiation of the experiment (Time period)	Duration completed at the time of sampling
	improving soil quality			
3	Farmers fields			
Name of the Centre: Hissar, Haryana				
Climatic zone: Hot arid				
Soil type: Aridisols (Deep loamy desert soils (inclusion of saline phase))				
1	Integrated nutrient supply for rainfed semiarid tropics in Pearl millet green gram (alternate strips)	PMT	1998	8 years
2	Organic farming studies on rainfed mustard	Organic farming	1997-2006	9 years
3	Tillage and nutrient management strategies for resource conservation and improving soil quality and productivity of rainfed pearl millet	Tillage	2001-2009	5 years
4	Cropping systems at Farmers fields			
C) Maize based production system				
Name of the Centre: Hoshiarpur, Punjab				
Climatic zone: Hot dry moist sub-humid				
Soil type: Inceptisols (deep, loamy to clayey alluvium derived (including saline and sodic phases))				
1	Integrated nutrient management practices in maize/black gram – wheat/lentil cropping systems under rainfed semi-arid tropics	INM	2000 Long term	6 years
2	Effect of tillage and sources of nitrogen on the crop productivity in maize-wheat cropping sequence under dryland conditions	Tillage	2000 Long term	6 years
3	Farmers field samples under different cropping systems			
Name of the Centre: Arjia, Rajasthan				
Climatic zone: Hot dry semi arid				
Soil type: Inceptisols (alluvium derived deep loamy grey brown)				
1	Low till farming strategies for resource conservation and improving soil quality	Tillage	1998 to LT	7 years
2	Integrated nutrient supply system for rainfed semiarid tropics	INM	1998 to LT	7 years
3	Farmers field samples under different cropping systems			

Name of the Centre: Rakhdhiansar,				
Climatic zone: Warm moist to dry sub humid				
Soil type: Inceptisols (medium to deep loamy to clayey brown forest and podzolic)				
1	Integrated nutrient supply system for rainfed semi-arid tropics under maize-black gram system	INM	1998 Long Term	7 years
2	Permanent manurial trial of maize	PMT	1995 Long term	10 years
3	Effect of FYM, green manuring with different doses of nitrogen on maize-wheat rotation	INM	2000 Long term	6 years
4	Tillage and nutrient management for resource conservation and improving soil quality in maize system	Tillage	2000 Long term	6 years
5	Farmers Fields			

NB: Total 20 experiments were assessed during this period in this project.

4.2.1.2. Important soil quality indicators sensitive to management practices chosen for the study at different centres:

The indicators chosen to assess the soil quality indices were: (1) physico-chemical and (2)chemical parameters viz., pH, electrical conductivity (EC), organic carbon (OC), available nitrogen (N), available phosphorus (P), available potassium (K), available sulphur (S), DTPA extractable zinc (Zn), iron (Fe), copper (Cu) manganese (Mn), DTPA sorbitol extractable boron (B); and (3) biological parameters viz., dehydrogenase assay (DHA), microbial biomass carbon (MBC) and labile carbon (LC); and the physical indicators viz., bulk density (BD) and mean weight diameter of the soil aggregates (MWD). The methods followed for the estimation of various parameters are given in Table 6.

Table 6: Protocol for measurement of soil quality indicators

Indicators	Method followed	Reference
pH	1:2 Soil water suspension	-
Electrical conductivity	1:2 Soil water suspension	Rhoades (1982)
Organic carbon	Wet oxidation with $H_2SO_4 + K_2Cr_2O_7$	Walkley and Black (1934)
Available N	Alkaline- $KMnO_4$ oxidizable N	Subbaiah and Asija (1956)
Available P	0.5M $NaHCO_3$ method	Olsen et al (1954)
Available K	Neutral normal ammonium acetate method	Hanway and Heidal (1952)
Exchangeable Ca, Mg	Neutral normal ammonium acetate method	-
DTPA exchangeable Zn, Fe, Cu, Mn	DTPA-$CaCl_2$-TEA using ICP	Lindsay and Norvell (1978)
Extractable Boron	DTPA-Sorbitol extraction	Miller *et al*., (2001)
Bulk density	Keen's Box Method	----
Aggregate stability	Wet sieve technique	Yoder (1936)
Mean weight diameter		Van Bavel, (1949)
Microbial biomass carbon	Fumigation extraction	Jenkinson and Powlson (1976)
Dehydrogenase activity	Triphenyl tetrazolium chloride method (TTC)	Lenhard (1956)
Labile carbon	$KMnO_4$ method	Weil et al (2003)

4.2.1.3. Sample collection, processing and measurement of Indicators

Soil samples collected from plough layer (0-20 cm depth) from the experimental sites at seven AICRPDA centres viz., Parbhani, Agra, Hissar, Sardar Krishinagar, Hoshiarpur, Arjia, and Rakhdhiansar were processed These samples were partitioned and passed through 8 mm, 4.75 mm, 2 mm, differently and used for further different kind of analysis. Soil samples passed through 8 mm sieve and retained on the 4.75 mm sieve were used for aggregate analysis using Yoder's apparatus. Soil samples passed through 2 mm sieve were used for chemical analysis for pH, EC, N, P, K, Ca, Mg, S, and micronutrients such as Zn, Fe, Cu, Mn and B. For biological parameters viz. microbial biomass carbon, labile C and enzymes such as dehydrogenase assay, samples were preserved at 4 to 5 ^oC. As it was not possible to visit the dryland centres every time, bulk density was measured by using Keene's box method.

4.2.1.4. Methodology for Computation of Soil Quality Index (SQI):

In order to identify the key soil quality indicators and computation of soil quality indices, principal component analysis (PCA) and linear scoring technique (LST) have been adopted. Principal component analysis method, being one of the robust techniques for selection of effective variables, helps in i) dimensionality reduction, ii) determination of linear combinations of variables, iii) choosing of the most useful variables, iv) visualization of multidimensional data, v) identification of underlying variables and vi) identification of groups of objects. These entire features knitted together make this PCA a powerful multivariate statistical tool to select the most appropriate soil quality indicators potential for the study area, from the list of indicators generated.

The steps involved during the computations were as follows:

1) Testing the level of significance for various soil indicator as influenced by various management treatments
2) Fixing or defining the goals
3) Selecting representative minimum data set (MDS) through Principal component analysis (PCA)
4) Correlation analysis among soil variables to reduce spurious grouping among highly weighted variables within each PC
5) Multiple regressions using the final MDS components as the independent variables and each goal attribute as a dependent variables
6) Scoring of the MDS indicators based on their performance of soil function and
7) Computation of soil quality indices (SQI)

The data on the entire chemical, physical and biological soil quality indicators were tested for their level of significance using the design in which the experiments were conducted, and the qualified variables were considered for further principal component analysis.

In order to identify the minimum data set (MDS), the procedures earlier suggested by Doran and Parkin (1994) and Andrews *et al*. (2002a) and followed by Sharma *et al*. (2005, 2008) were used. Subsequent to the test of level of significance, the data were subjected to principal component analysis. Principal component analysis (PCA) was employed as a data reduction tool to select the most appropriate indicators. Principal components (PC) for a data set are defined as linear combinations of variables that account for maximum variance within the set by describing vectors of closet fit to the ‘n’ observation in p-dimensional space, subject to being orthogonal to one another. The objective of PCA was to reduce the dimensionality (number of variables) of the dataset but retain most of the original variability in the data. This PC analysis transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible.

Those principal components which received higher eigen values and variables which had high factor loading were considered as the best representative of system attributes. As per the criteria set by Brejda *et al*. (2000a, b), only the PCs with eigen values ≥ 1 and those which explained at least 5% of the variation in the data (Wander and Bollero, 1999) were considered. Within each PC, only highly weighted factors (having absolute values within 10% of the highest factor loading) were retained for MDS. When more than one factor was retained under a single PC, multivariate correlation coefficients were used to determine if the variables could be considered redundant and therefore eliminated from the MDS (Andrews *et al*., 2002a). Among the well-correlated variables ($r > 0.70$), only one variable was considered for the MDS. However, flexibility criteria were also followed in most of the circumstances depending upon the importance of the variables. If the highly weighted variables were not correlated, each was considered important and was retained in the MDS. In the absence of adequacy of the long-term replicated yield data from centres, multiple regression analysis with functional goals could not be performed. As suggested by one of the international reviewer's viz., Jenny Fegent, Managing Editor of Australian Journal of Soil Research, Collingwood, Australia, flexible criteria was adopted. The variables qualified under these series of steps were termed as the key indicators and were considered for computation of soil quality index after suitable transformation and scoring.

After identifying the MDS indicators, every observation of each MDS indicator was transformed using a linear scoring method as suggested by Andrews *et al.* (2002a). To assign the scores, indicators were arranged in order depending on whether a higher value was considered "good" or "bad" in terms of soil function. In case of 'more is better' indicators, each observation was divided by the highest observed value such that the highest observed value received a score of 1. For 'less is better' indicators, the lowest observed value (in the numerator) was divided by each observation (in the denominator) such that the lowest observed value received a score of 1. After transformation using linear scoring, the MDS indicators for each observation were weighted using the PCA results. Each PC explained a certain amount (%) of the variation in the total data set. This percentage when divided by the total percentage of variation explained by all PCs with eigenvectors > 1, gave the weighted factors for indicators chosen under a given PC. After performing these steps, to obtain soil quality index (SQI), the weighted MDS indicator scores for each observation were summed up using the following relation:

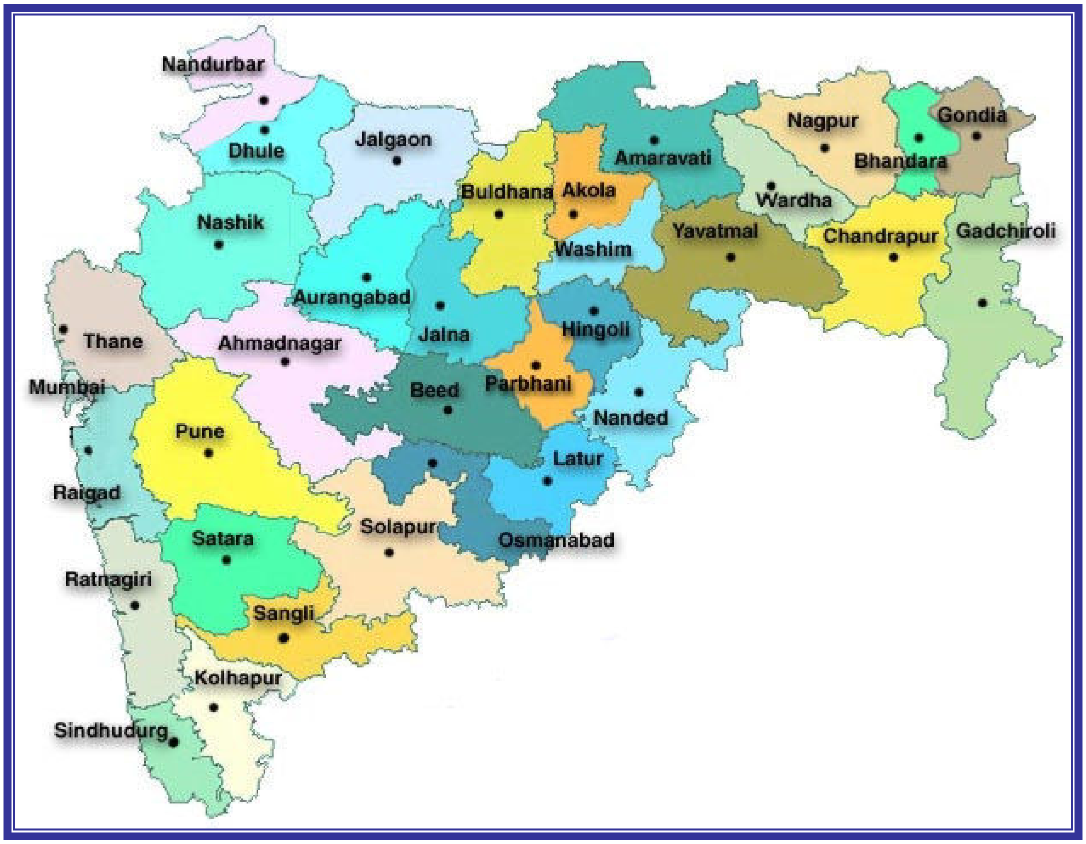
$$SQI = \sum_{i=1}^{n} (Wi \times Si)$$

Where Si is the score for the subscripted variable and Wi is the weighing factor obtained from the PCA. Here the assumption is that higher index scores meant better soil quality or greater performance of soil function. For better understanding and relative comparison of the long-term performance of the conjunctive nutrient use treatments, the SQI values were reduced to a scale of 0 – 1 by dividing all the SQI values with the highest SQI value. The numerical values so obtained clearly reflect the relative performance of the management treatments, hence were termed as the relative soil quality indices (RSQI). Further, the percent contributions of each final key indicator were also calculated.

AICRPDA Centres

Pharbhani Centre

Rabi Sorghum based production system



4.2.3. Effect of predominant soil and nutrient management practices on soil quality indicators (attributes) and soil quality indices at Parbhani centre of AICRPDA

Location description, climate and soil characteristics

Parbhani center is located in central and western Maharashtra Plateau (AESR 6.2) in hot moist semiarid ecological sub region with mean annual rainfall of 961 mm, shallow and medium loamy to clayey black soils (70-100 cm), pH (8.2) having bulk density of (1.29 gcm^{-3}) and medium to high AWC (32-33%), LGP120-150 days. The frequency of occurrence of drought in this region is 8 out of 18 years. The predominant kharif crops of this region are sorghum, cotton, pigeon pea, mung bean, blackgram, pearl millet and soybean. The major rabi crops grown in this area are sorghum, safflower, chickpea and sunflower. This centre serves the research information needs of Nashik, Dhule, Aurangabad, Jalna, Nanded, Parbhani, Latur, Northern hilly part of Ahmadnagar and Jalgaon (western part).

In order to study the effect of predominant soil and nutrient management practices on soil quality indicators, and the soil quality indices, the following experiments were chosen at Parbhani centre.

- Experiment 1: Organic farming comprising of INM treatments and legume based cropping systems

The four cropping systems adopted were

i. Sorghum + pigeon pea (4:2)
ii. Soybean + pigeon pea (4:2)
iii. Cotton + black gram (1:1) and
iv. Mung bean + rabi sorghum.

4.2.4. Experiment 1: Organic farming comprising of INM treatments and legume based cropping systems

This long term experiment on organic farming comprising of INM treatments and legume based cropping systems was initiated during the year 2000 at the experimental station to improve soil quality for sustainable production and this experiment was adopted for assessment of soil quality. Soils were typic chromusterts. The four cropping systems adopted were i) sorghum + pigeon pea (4:2), ii) soybean + pigeon pea (4:2), iii) cotton + black gram (1:1) and iv) mung bean + rabi sorghum. The seven nutrient management treatments tested under these cropping systems were F1: FYM@ 5 t ha^{-1}; F2: Gliricidia @ 3t ha^{-1} (semi dried); F3: Recommended dose of fertilizer (RDF); F4: 25% RDF + FYM @ 2.5 t ha^{-1}; F5: 25% RDF + gliricidia @ 1.5 t ha^{-1}; F6: Control with rotation and F7: Absolute control without rotation. Soil quality assessment studies were taken up in these experiments after five years of experimentation.

4.2.5. Sorghum + pigeon pea (4:2) system

The data obtained on various soil quality parameters are presented in Tables 7 to 9. The soil reaction in this system varied from 7.78 to 8.18 and the electrical conductivity ranged from 0.14 to 0.22 d Sm^{-1} across the treatments. Organic carbon was highest under application of 25% RDF + FYM @ 2.5 t ha^{-1} (F4) followed by recommended dose of fertilizer (RDF) (F3) while the lowest content was observed under control with rotation (F6) (Fig 1).

Available N content varied between 180.1 to 203.6 kg ha^{-1} and the treatments did not differ significantly in influencing the available N contents. But, available P was significantly influenced by the treatments and application of recommended dose of fertilizer (RDF) (F3) recorded the highest available P of 16.5 kg ha^{-1} which was at par with that with Gliricidia applied @ 3t ha^{-1} (semi dried) (F2) (13.2 kg ha^{-1}) while the lowest was recorded with control with rotation (F6) (5.0 kg ha^{-1}). Treatments significantly influenced available K content in soils with gliricidia applied @ 3t ha^{-1} (semi dried) (F2) recording significantly highest available K content of 702.4 kg ha^{-1} which was at par with FYM @ 5 t ha^{-1} (665.7 kg ha^{-1}) while the lowest was observed under absolute control (500.9 kg ha^{-1}) (Fig 2).

Exchangeable Ca and Mg were not significantly influenced by the treatments; however, their content ranged between 6.02 to 6.84 c mol kg^{-1} and 4.51 to 5.23 c mol kg^{-1} respectively across the various treatments. Available sulphur was also significantly influenced by the treatments and the highest available S of 28.3 kg ha^{-1} was recorded under FYM applied @ 5 t ha^{-1} (F1) followed by gliricidia applied @ 3t ha^{-1} (semi dried) (F2) while the lowest amount of 13.0 kg ha^{-1} was observed under absolute control without rotation (F7) (Fig 3). The micronutrient contents viz., Zn, Fe, Cu, Mn and B were not significantly influenced by the management treatments. However, available Zn, Fe Cu, Mn and B ranged between 0.22 to 0.30, 9.4 to 11.5, 1.26 to 1.47, 18.5 to 22.1 and 1.09 to 1.25 µg g^{-1} of soil respectively (Fig 4).

The biological soil quality indicators viz., dehydrogenase assay (DHA), microbial biomass carbon (MBC) and labile carbon (LC) were significantly influenced by the treatments. Among all the treatments, application of 25% RDF + FYM @ 2.5 t ha^{-1} (F4) recorded the highest DHA of 2.41 µg TPF g^{-1} of soil hr^{-1}, MBC of 232.6 µg g^{-1} of soil and LC of 271.8 µg g^{-1} of soil, while absolute control without rotation (F7) recorded the lowest (Fig 5). Among the physical soil quality indicators, bulk density varied from 1.19 to 1.36 Mg m^{-3} and was not conspicuously influenced by the nutrient management treatments. The mean weight diameter ranged from 0.26 to 0.36 mm the highest being under application of FYM @ 5 t ha^{-1} (0.36 mm) (Fig 6).

Table 7: Effect of different INM treatments on physico-chemical and chemical (macronutrients) soil quality parameters under Sorghum + pigeon pea (4:2) system in Vertisol at Parbhani

SNo	Name of the treatments	pH	EC dS m^{-1}	OC g kg^{-1}	N	P	K
					kg ha^{-1}		
1	F1: FYM@ 5 t ha^{-1}	7.80	0.17	5.99	195.8	10.9	665.7
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	7.78	0.22	5.69	203.6	13.2	702.4
3	F3: RDF	8.16	0.17	6.17	193.5	16.5	572.6
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	7.94	0.17	6.72	198.3	12.7	573.1
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	7.95	0.17	5.93	196.2	10.3	608.3
6	Control with rotation	8.18	0.15	5.00	185.9	8.5	525.0
7	Absolute control without rotation	7.84	0.14	5.69	180.1	9.6	500.9
	CD @ 0.05	NS	0.02	0.51	NS	3.9	100.8

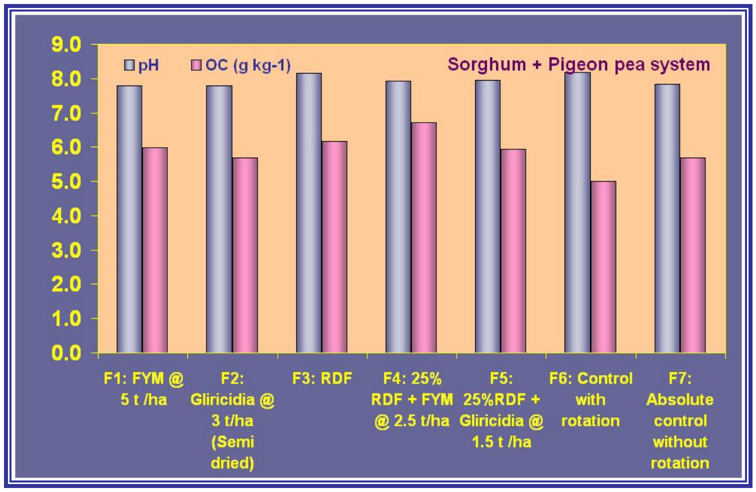


Fig 1: Effect of INM treatments on pH and organic carbon under sorghum + pigeon pea system in Vertisols at Parbhani

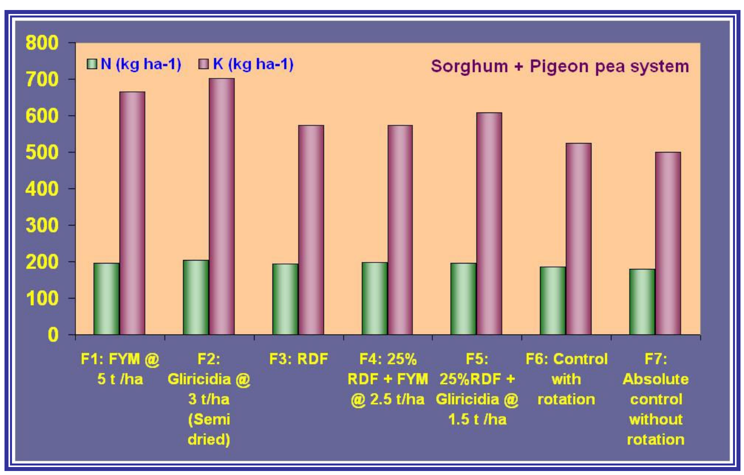


Fig 2: Effect of INM treatments on chemical soil quality parameters (macronutrients) under sorghum + pigeon pea system in Vertisols at Parbhani

Table 8: Effect of different INM treatments on chemical soil quality parameters (secondary and micronutrients) under Sorghum + pigeon pea (4:2) system in Vertisol at Parbhani

SNo	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		C mol kg^{-1}		kg ha^{-1}	µg g^{-1} of soil				
1	F1: FYM@ 5 t ha^{-1}	6.04	5.23	28.3	0.29	11.5	1.40	21.8	1.24
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	6.12	5.09	19.5	0.27	11.3	1.34	21.5	1.24
3	F3: RDF	6.02	4.66	18.2	0.30	10.8	1.44	21.2	1.25
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	6.07	4.70	15.2	0.28	10.9	1.44	22.1	1.18
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	6.21	5.19	15.6	0.29	10.7	1.47	21.5	1.16
6	Control with rotation	6.46	4.59	16.6	0.22	9.9	1.29	19.9	1.13
7	Absolute control without rotation	6.84	4.51	13.0	0.23	9.4	1.26	18.5	1.09
	CD @ 0.05	NS	NS	3.05	NS	NS	NS	NS	NS

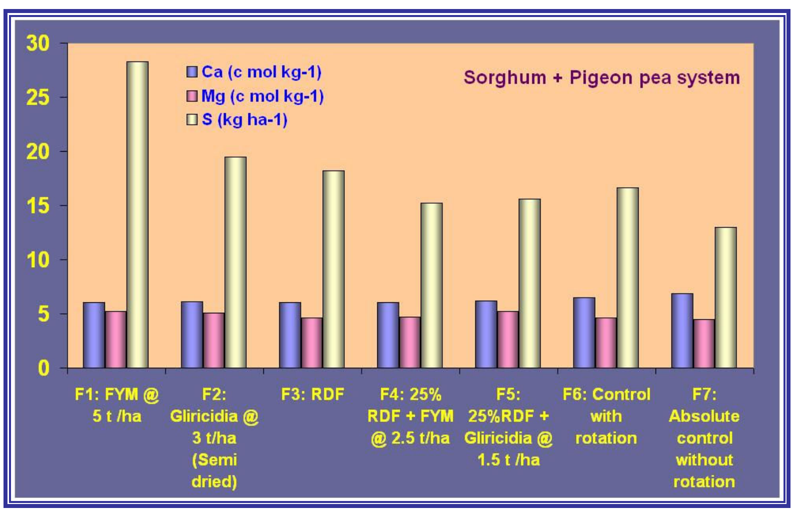


Fig 3: Effect of INM treatments on chemical soil quality parameters (secondary nutrients) under sorghum + pigeon pea system in Vertisol at Parbhani

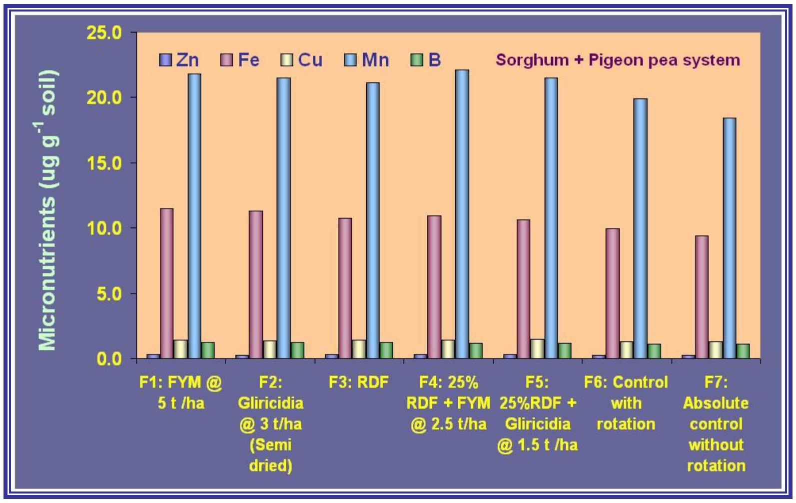


Fig 4: Effect of INM treatments on chemical soil quality parameters (micronutrients) under sorghum + pigeon pea system in Vertisol at Parbhani

Table 9: Effect of different INM treatments on biological and physical soil quality parameters under Sorghum + pigeon pea (4:2) system in Vertisol at Parbhani

SNo	Name of the treatments	DHA (µg TPF g^{-1} soil hr^{-1})	MBC (µg g^{-1} soil)	LC (µg g^{-1} soil)	BD (Mg m^{-3})	MWD (mm)
1	F1: FYM@ 5 t ha^{-1}	2.15	203.0	260.7	1.19	0.36
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	2.07	209.8	263.2	1.23	0.33
3	F3: RDF	2.30	197.4	244.9	1.29	0.30
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	2.41	232.6	271.8	1.21	0.33
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	2.38	231.6	259.2	1.26	0.30
6	Control with rotation	1.15	190.5	207.3	1.36	0.28
7	Absolute control without rotation	1.14	163.6	199.1	1.32	0.26
	CD @ 0.05	0.14	26.4	34.8	NS	0.04

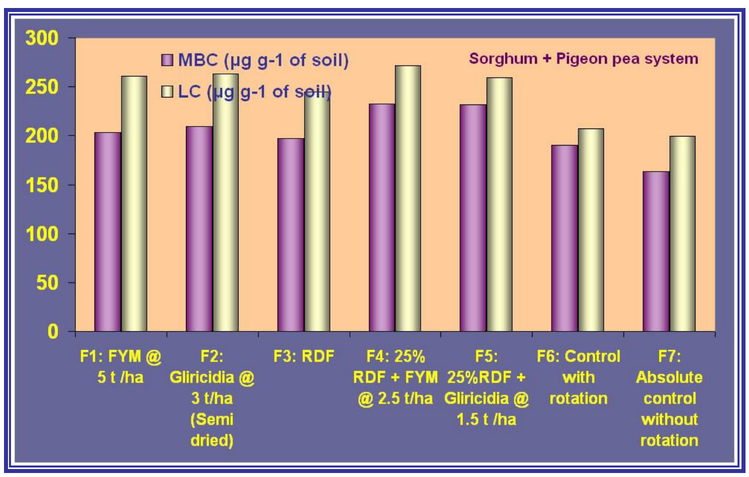


Fig 5: Effect of INM treatments on biological soil quality parameters under sorghum + pigeon pea system in Vertisol at Parbhani

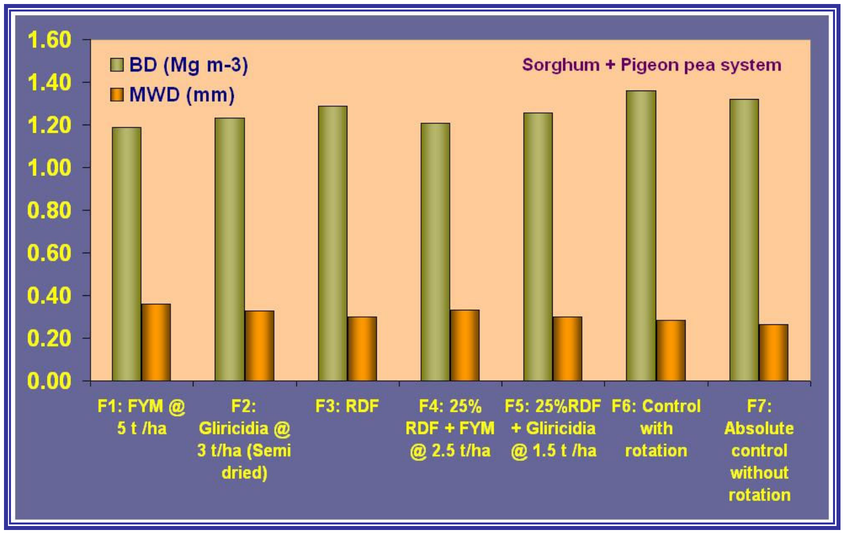


Fig 6: Effect of INM treatments on physical soil quality parameters under sorghum + pigeon pea system in Vertisol at Parbhani

4.2.5.1. Key indicators and soil quality assessment

4.2.5.2. Results of principal component analysis

The long-term influence of INM treatments practiced under sorghum + pigeon pea system on 19 soil quality indices has been statistically analyzed and it was observed that out of 19 soil quality parameters, ten variables were not significant and hence, these were dropped and the PCA analysis was carried out with only nine variables. In the PCA of 9 variables, only two PCs had eigen values >1 and explained 68.9% variance in the data set (Table 10). In PC1 the highly weighted variables were dehydrogenase assay, labile carbon and mean weight diameter while in PC2, only two variables viz., organic carbon and available nitrogen were the highly weighted variables. Correlation analysis was run for the variables qualified under PC1 (Table 11). Though, DHA as well as labile carbon had significant and good correlations, both were retained for the final minimum data set. On the other hand, mean weight diameter also had significant correlation, but the ‘r’ value was below 0.70 and hence was retained for the minimum data set. The highly weighted variables under PC2 revealed no significant correlation and hence were considered for final MDS. On the whole, surprisingly very few indicators viz., organic carbon, available S, dehydrogenase assay, labile carbon and mean weight diameter were retained for the final MDS and termed as the key indicators for sorghum + pigeon pea system and these indicators were used for computing the soil quality indices.

Table 10: Principal component analysis of soil quality parameters as influenced by different INM treatments under sorghum + pigeon pea system in Vertisol at Parbhani

	PC1	PC2
Total Eigen values	4.678	1.524
% of Variance	51.975	16.934
Cumulative %	51.975	68.909
Eigen Vectors		
EC	0.743	0.248
OC	0.597	**-0.615**
P	0.539	-0.282
K	0.700	0.500
S	0.512	**0.641**
DHA	**0.890**	-0.297
MBC	0.705	-0.396
LC	**0.887**	-0.055
MWD	**0.807**	0.309

Table 11: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs			
PC1	**DHA**	**LC**	**MWD**
DHA	1.00	0.805**	0.573**
LC	0.805**	1.00	0.696**
MWD	0.573**	0.696**	1.00
Correlation sum	2.378	2.501	2.269
PC2	**OC**	**S**	
OC	1.00	0.092	
S	0.092	1.00	
Correlation sum	1.092	1.092	

4.2.5.3. Soil quality indices

Soil quality indices were computed using five key soil quality indicators viz., organic carbon, available S, dehydrogenase assay, labile carbon and mean weight diameter. The soil quality indices varied from 1.68 to 2.47 across the INM treatments (Table 12 & Fig 7). Among all the INM treatments, significantly highest soil quality index was observed with application of FYM@ 5 t ha^{-1} (2.47) which was at par with 25% RDF + FYM@ 2.5 t ha^{-1} (2.43). It was observed that the treatments which received FYM showed the highest soil quality which was followed by the treatments which received gliricidia component. Irrespective of their statistical significance, the relative order of performance of treatments in terms of influencing soil quality were: F1: FYM@ 5 t ha^{-1} (2.47) > F4: 25% RDF + FYM@ 2.5 t ha^{-1} (2.43) > F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1} (2.31) > F2: Gliricidia @ 3 t ha^{-1} (semi dried) (2.30) > F3: RDF (2.27) > Control with rotation

(1.75) > Absolute control without rotation (1.68). The soil quality indices when reduced to a scale of 1.00 varied from 0.66 to 0.97 across the INM treatments. The percent contributions of key indicators towards soil quality indices were: Mean weight diameter (29%), labile carbon (28%), dehydrogenase assay (26%), organic carbon (10%) and available S (7%) (Fig 8).

Table 12: Soil quality indices as influenced by different INM treatments under Sorghum + pigeon pea (4:2) system in Vertisol at Parbhani

SNo	Name of the treatments	SQI	RSQI
1	F1: FYM@ 5 t ha^{-1}	2.47	0.97
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	2.30	0.90
3	F3: RDF	2.27	0.89
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	2.43	0.96
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	2.31	0.90
6	Control with rotation	1.75	0.69
7	Absolute control without rotation	1.68	0.66
	CD @ 0.05	0.15	0.06

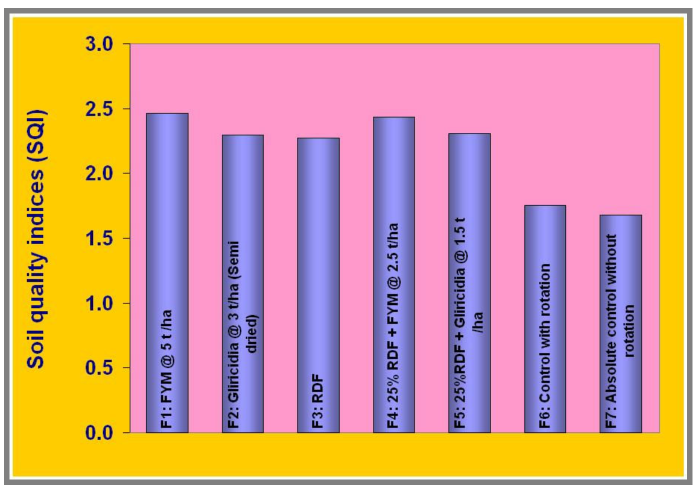


Fig 7: Soil quality indices as influenced by different INM treatments under Sorghum + pigeon pea (4:2) system in Vertisol at Parbhani

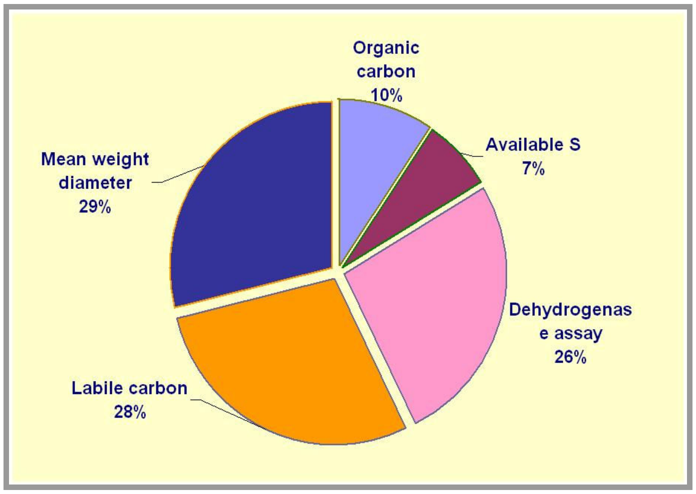


Fig 8: Percent contributions of key indicators towards soil quality indices as influenced by under sorghum + pigeon pea system in Vertisol at Parbhani

4.2.6 Soybean + pigeon pea (4:2) system

The data obtained on various soil quality parameters under soybean + pigeon pea (4:2) system is presented in Tables 13 to 15. In soybean + pigeon pea (4:2) system, soil reaction was significantly influenced by the treatments and varied from 7.60 to 8.05. Electrical conductivity varied from 0.14 to 0.18 d S m^{-1} across the treatments. The soil organic carbon content was also not influenced by the INM treatments, but varied from 5.99 to 6.90 g kg^{-1} (Fig 9).

Available N was significantly influenced by the nutrient management treatments and the highest available N content of 217.3 kg ha^{-1} was recorded under application of 25% RDF + gliricidia @ 1.5 t ha^{-1} (F5) which was at par with gliricidia applied @ 3t ha^{-1} (semi dried) (F2) and application of recommended dose of fertilizer (+RDF) (F3), while the lowest (180.7 kg ha^{-1}) was observed under absolute control without rotation (F7). The available P content varied between 12.4 to 15.3 kg ha^{-1} across the treatments and was not significantly influenced by the INM treatments. Available K content was significantly influenced by the INM treatments with the highest value under gliricidia applied @ 3 t ha^{-1} which was at par with FYM @ 5 t ha^{-1} (660.2 kg ha^{-1}). Absolute control plot recorded the lowest available K content of 482.8 kg ha^{-1} (Fig 10).

Table 13: Effect of different INM treatments on physico chemical and chemical soil quality parameters under Soybean + pigeon pea (4:2) system in Vertisol at Parbhani

SNo	Name of the treatments	pH	EC dS m^{-1}	OC g kg^{-1}	N	P	K
					kg ha^{-1}		
1	F1: FYM@ 5 t ha^{-1}	7.90	0.17	6.90	194.4	14.23	660.2
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	7.65	0.16	6.75	203.5	13.77	735.9
3	F3: RDF	7.85	0.17	6.13	205.3	15.28	539.4
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	7.70	0.16	6.39	193.5	15.03	562.3
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	8.05	0.18	6.65	217.3	13.60	650.4
6	Control with rotation	7.65	0.14	6.04	184.1	12.81	520.9
7	Absolute control without rotation	7.60	0.15	5.99	180.7	12.43	482.8
	CD @ 0.05	0.24	NS	NS	22.2	NS	107.7

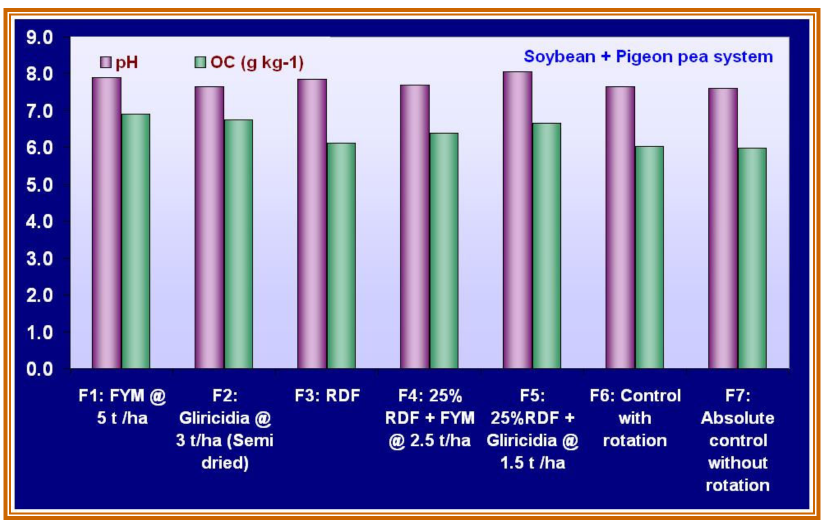


Fig 9: Effect of different INM treatments on pH and organic carbon under Soybean + pigeon pea (4:2) system in Vertisol at Parbhani

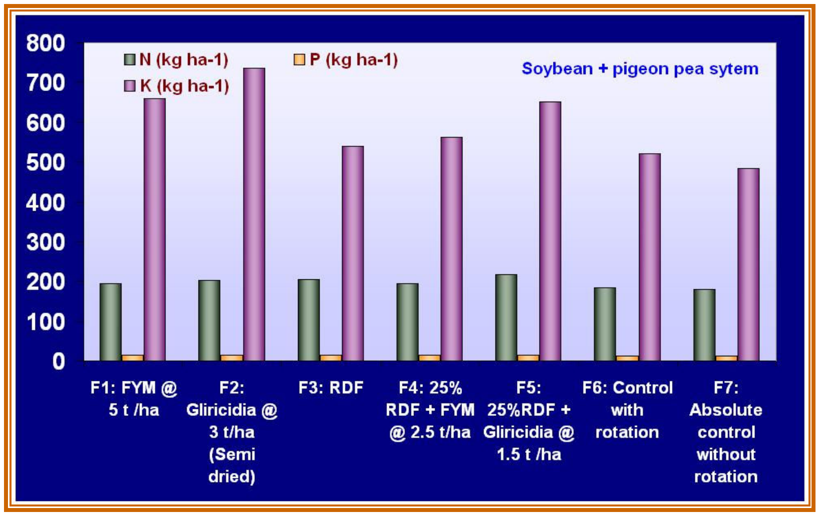


Fig 10: Effect of different INM treatments on chemical soil quality parameters (macronutrients) under Soybean + pigeon pea (4:2) system in Vertisol at Parbhani

Exchangeable Ca and Mg varied from 6.26 to 6.67 and 4.58 to 5.60 c mol kg^{-1} and no conspicuous influence of the INM treatments was observed on these parameters. Available S was significantly influenced by the treatments and application of 25% RDF + FYM @ 2.5 t ha^{-1} (F4) recorded the highest available S content of 20.2 kg ha^{-1} followed by application of recommended dose of fertilizer (RDF) (F3) (17.4 kg ha^{-1}), while the lowest available S (12.0 kg ha^{-1}) was recorded under application of 25% RDF + gliricidia @ 1.5 t ha^{-1} (F5) (Fig 11). The micronutrient contents except available Mn were not significantly influenced by the INM treatments under soybean + pigeon pea system. However, available Zn, Fe, Cu and B ranged between 0.25 to 0.30, 9.6 to 11.5, 1.32 to 1.48, and 0.99 to 1.20 µg g^{-1} of soil. Available Mn was found to be significantly highest under application of 25% RDF + FYM @ 2.5 t ha^{-1} (F4) (23.2 µg g^{-1} of soil) which was found to be at par with many other treatments while the lowest available Mn of 18.3 µg g^{-1} soil was recorded under absolute control without rotation (F7) (Fig 12).

Table 14: Effect of different INM treatments on chemical soil quality parameters (secondary and micronutrients) under Soybean + pigeon pea (4:2) system in Vertisol at Parbhani

SNo	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		C mol kg^{-1}		kg ha^{-1}	µg g^{-1} soil				
1	F1: FYM@ 5 t ha^{-1}	6.34	4.94	13.5	0.28	11.4	1.42	22.7	1.13
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	6.67	4.96	12.3	0.27	11.5	1.47	22.7	0.99
3	F3: RDF	6.26	5.25	17.4	0.30	10.1	1.48	22.1	1.20
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	6.34	5.60	20.2	0.29	10.4	1.42	23.2	1.07
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	6.28	5.26	12.0	0.27	11.1	1.46	21.2	1.18
6	Control with rotation	6.26	4.58	17.2	0.26	9.7	1.39	19.7	1.08
7	Absolute control without rotation	6.26	4.72	12.6	0.25	9.6	1.32	18.3	1.08
	CD @ 0.05	NS	NS	2.2	NS	NS	NS	2.6	NS

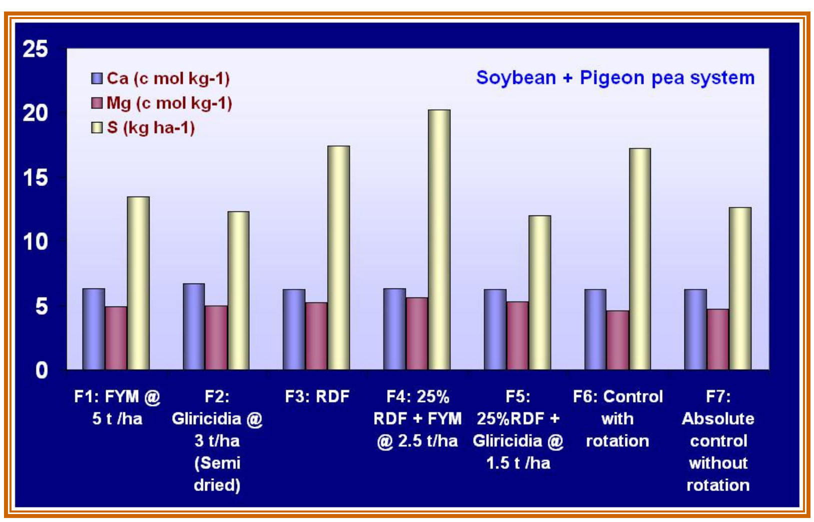


Fig 11: Effect of different INM treatments on chemical soil quality parameters (secondary nutrients) under Soybean + pigeon pea (4:2) system in Vertisol at Parbhani

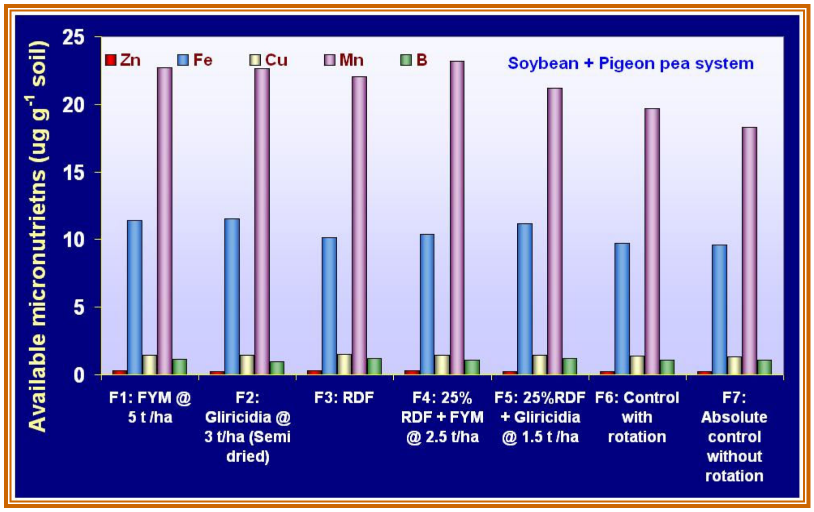


Fig 12: Effect of different INM treatments on chemical soil quality parameters (micronutrients) under Soybean + pigeon pea (4:2) system in Vertisol at Parbhani

Among the biological soil quality parameters, DHA was significantly influenced by the INM treatments and was found to be highest (2.44 µg TPF g^{-1} soil hr^{-1}) under FYM@ 5 t ha^{-1} followed by application of 25% RDF + gliricidia @ 1.5 t ha^{-1} (F5) while the lowest DHA of 1.51 µg TPF g^{-1} soil hr^{-1} was recorded under absolute control without rotation (F7). Microbial biomass carbon (MBC) was also found to be significantly influenced by the management treatments but the highest MBC was found under application of 25% RDF + gliricidia @ 1.5 t ha^{-1} (F5) (252.9 µg g^{-1} soil) and was found to be at par with FYM@ 5 t ha^{-1}, gliricidia applied @ 3t ha^{-1} (semi dried) (F2) and application of 25% RDF + FYM @ 2.5 t ha^{-1} (F4). The lowest amount of MBC of 182.5 µg g^{-1} soil) was recorded under absolute control without rotation (F7). Labile carbon was significantly influenced by the management treatments and varied between 219.5 to 277.9 µg g^{-1} soil. Among all the treatments, application of gliricidia @ 3 t ha^{-1} recorded significantly highest LC of 277.9 µg g^{-1} soil which was at par with FYM @ 5 t ha^{-1} (271.4 µg g^{-1} soil) (Fig 13).

The physical soil quality indicators viz., bulk density and mean weight diameter were significantly influenced by the management treatments. It was quite interesting to note that, sole organic treatments FYM@ 5 t ha^{-1} and gliricidia applied @ 3 t ha^{-1} (semi dried (F2) recorded significantly lowest bulk density of 1.12 Mg m^{-3} and the highest MWD of 0.48 mm under FYM @ 5 t ha^{-1} (Fig 14).

Table 15: Effect of different INM treatments on biological and physical soil quality parameters under Soybean + pigeon pea (4:2) system in Vertisol at Parbhani

SNo	Name of the treatments	DHA (µg TPF g^{-1} soil hr^{-1})	MBC (µg g^{-1} soil)	LC (µg g^{-1} soil)	BD (Mg m^{-3})	MWD (mm)
1	F1: FYM@ 5 t ha^{-1}	2.44	242.5	271.4	1.12	0.48
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	2.16	237.6	277.9	1.12	0.41
3	F3: RDF	1.92	226.6	259.5	1.14	0.30
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	2.00	243.5	266.4	1.14	0.33
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	2.18	252.9	260.6	1.13	0.42
6	Control with rotation	1.70	211.5	220.3	1.18	0.27
7	Absolute control without rotation	1.51	182.5	219.5	1.22	0.25
	CD @ 0.05	0.24	22.2	26.9	0.06	0.04

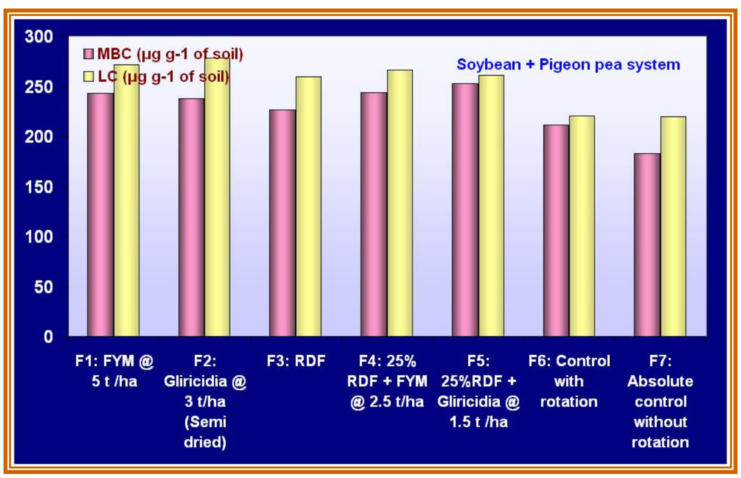


Fig 13: Effect of different INM treatments on biological soil quality parameters under Soybean + pigeon pea (4:2) system in Vertisol at Parbhani

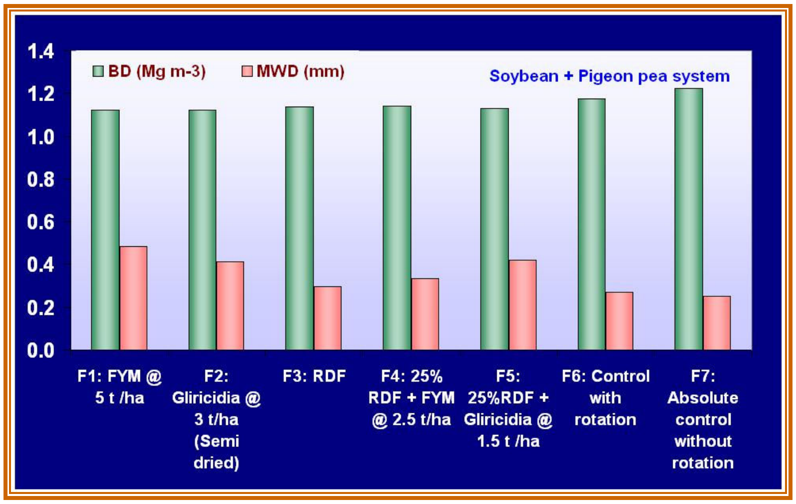


Fig 14: Effect of different INM treatments on physical soil quality parameters under soybean + pigeon pea (4:2) system in Vertisol at Parbhani

4.2.6.1. Key indicators and soil quality assessment

4.2.6.2. Results of principal component analysis

The long-term influence of INM treatments practiced under Soybean + pigeon pea (4:2) system on 19 soil quality indices has been statistically analyzed. It was observed that out of 19 soil quality parameters, nine variables were insignificant and hence, these were dropped. The PCA analysis was carried out with only ten variables in which only three PCs had eigen values >1 and explained 78.6% variance in the data set (Table 16). In PC1, the highly weighted variables were dehydrogenase assay, microbial biomass carbon, labile carbon and mean weight diameter. It was observed that all the biological parameters included in the study were highly weighted in this PC. Hence, a correlation analysis was carried out between the variables (Table 17) qualified under PC1, which revealed a significant correlation between the variables. Dehydrogenase assay had the highest correlation sum among all the variables and hence was retained for the final MDS. But the correlation value for dehydrogenase assay and labile carbon was below the set criteria of significance (0.70) and hence, LC was also retained for the minimum data set. As MBC was observed to have good significance with both DHA as well as LC, it was not retained for the MDS. Mean weight diameter, having the second highest correlation sum of 3.20, though had significant and good correlation with DHA, was retained for the MDS because of its importance as a physical soil quality indicator for these Vertisols. In PC2 and PC3, only single variables viz., available S as well as soil pH were highly weighted respectively and hence were retained for the MDS. Hence, the final indicators retained for the minimum data set included pH, available S, dehydrogenase assay, labile carbon and mean weight diameter and were termed as the key indicators for soybean + pigeon pea (4:2) system in Vertisol at Parbhani.

Table 16: Principal component analysis of soil quality parameters as influenced by different INM treatments under soybean + pigeon pea (4:2) system in Vertisol at Parbhani

	PC1	PC2	PC3
Total Eigen values	5.257	1.594	1.006
% of Variance	52.573	15.938	10.062
Cumulative %	52.573	68.511	78.573
Eigen Vectors			
pH	0.554	0.022	**-0.787**
N	0.559	-0.346	0.169
K	0.745	-0.286	0.358
S	-0.187	**0.912**	0.068
Mn	0.675	0.511	0.254
DHA	**0.888**	-0.096	-0.121
MBC	**0.861**	0.266	-0.178
LC	**0.828**	0.037	0.328
BD	-0.775	-0.374	0.032
MWD	**0.882**	-0.277	-0.080

Table 17: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs				
PC1	**DHA**	**MBC**	**LC**	**MWD**
DHA	1.00	0.739**	0.662**	0.902**
LC	0.739**	1.00	0.710**	0.655**
MBC	0.662**	0.710**	1.00	0.646**
MWD	0.902**	0.655**	0.646**	1.00
Correlation sum	**3.30**	**3.10**	**3.02**	**3.20**

4.2.6.3. Soil quality indices

Soil quality indices were computed using five key soil quality indicators viz., pH, available S, dehydrogenase assay, labile carbon and mean weight diameter, which varied from 1.48 to 2.16 across the INM treatments (Table 18 & Fig 15). The treatment which received FYM@ 5 t ha^{-1} maintained significantly highest soil quality index of 2.16 followed by the application of Gliricidia @ 3 t ha^{-1} (semi dried) (2.00). Irrespective of their statistical significance, the relative order of performance of treatments in terms of influencing soil quality were: F1: FYM@ 5 t ha^{-1} (2.16) > F2: Gliricidia @ 3 t ha^{-1} (semi dried) (2.00) > F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1} (1.97) > F4:

25% RDF + FYM@ 2.5 t ha^{-1} (1.90) > F3: RDF (1.79) Control with rotation (1.60) > Absolute control without rotation (1.48). The soil quality indices when reduced to a scale of 1.00 varied from 0.68 to 0.99 across the INM treatments. The percent contributions of key indicators towards soil quality indices were: pH (7%), available S (8%), dehydrogenase assay (29%), labile carbon (31%) and mean weight diameter (25%) (Fig 16).

Table 18: Soil quality indices as influenced by different INM treatments under Sorghum + pigeon pea (4:2) system in Vertisol at Parbhani

SNo	Name of the treatments	SQI	RSQI
1	F1: FYM@ 5 t ha^{-1}	2.16	0.99
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	2.00	0.92
3	F3: RDF	1.79	0.82
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	1.90	0.87
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	1.97	0.90
6	Control with rotation	1.60	0.74
7	Absolute control without rotation	1.48	0.68
	CD @ 0.05	0.08	0.05

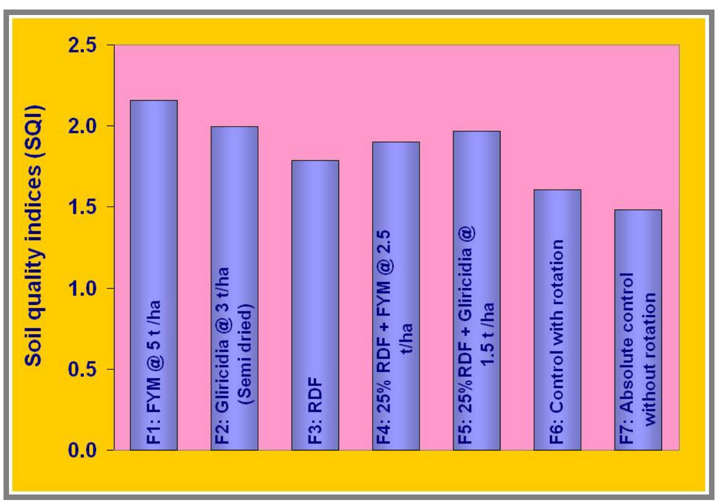


Fig 15: Soil quality indices as influenced by different INM treatments under Sorghum + pigeon pea (4:2) system in Vertisol at Parbhani

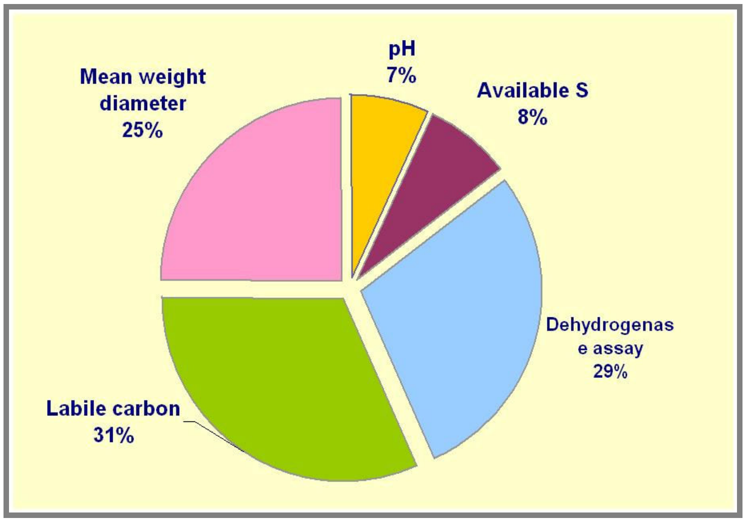


Fig 16: Percent contribution of key indicators towards soil quality indices under sorghum + pigeon pea (4:2) system in Vertisol at Parbhani

4.2.7. Cotton + black gram (1:1) system

The data obtained on various soil quality parameters under cotton + black gram (1:1) system is presented in Tables 19 to 21.

The soil reaction under cotton + black gram system was found to be slightly alkaline in range and varied from 7.71 to 8.19. Electrical conductivity of the soils ranged between 0.14 to 0.17 dS m^{-1}. Organic carbon was found to be medium and ranged between 5.74 to 6.50 g kg^{-1}. The INM treatments significantly influenced the organic carbon content and FYM@ 5 t ha^{-1} (F1) recorded the highest organic carbon content of 6.50 g kg^{-1} which was at par with application of 25% RDF + gliricidia @ 1.5 t ha^{-1} (F5) while the lowest organic carbon content was recorded under control with rotation (F6) and absolute control without rotation (F7) (Fig 17).

Available N, P and K were significantly influenced by the INM treatments with mean values ranging from 170.6 to 206.1 kg ha^{-1}, 12.5 to 16.7 kg ha^{-1} and 543.1 to 774.4 kg ha^{-1} respectively. Among the INM treatments, gliricidia applied @ 3t ha^{-1} (semi dried) (F2) recorded significantly highest available N (206.1 kg ha^{-1}), application of recommended dose of fertilizer (RDF) (F3) recorded the highest available P of 16.7 kg ha^{-1} while application of 25% RDF + gliricidia @ 1.5 t ha^{-1} (F5) recorded the highest available K content of 774.5 kg ha^{-1} (Fig 18). Exchangeable Ca and

Mg were not significantly influenced by the INM treatments. However, their contents varied from 6.09 to 6.43 and 4.60 to 5.23 c mol kg^{-1} respectively. Available sulphur was significantly influenced by the INM treatments and the highest available S was recorded under FYM@ 5 t ha^{-1} (19.0 kg ha^{-1}) while the lowest was recorded under application of recommended dose of fertilizer (RDF) (F3) (13.9 kg ha^{-1}) (Fig 19).

The influence of INM treatments on micronutrient content was similar to that as was observed under soybean + pigeon pea system where available Mn was found to be significantly influenced by INM treatments while this effect was not observed in case of available Zn, Fe, Cu and B. Highest available Mn was observed under application of 25% RDF + gliricidia @ 1.5 t ha^{-1} (F5) (23.5 µg g^{-1} of soil) which was at par with other INM treatments while the lowest amount (18.6 µg g^{-1} of soil) was observed under absolute control without rotation (F7). Though not-significantly influenced, available Zn, Fe, Cu and B varied from 0.23 to 0.28, 8.70 to 11.2, 1.33 to 1.49 and 1.04 to 1.21 µg g^{-1} of soil respectively (Fig 20).

Among the biological parameters, dehydrogenase activity was significantly influenced by the INM treatments and was found to be highest under application of 25% RDF + FYM @ 2.5 t ha^{-1} (F4) (2.58 µg TPF g^{-1} soil hr^{-1}) followed by application of recommended dose of fertilizer (RDF) (F3) (Fig 21). Microbial biomass carbon (MBC) was also significantly influenced by the management treatments and application of 25% RDF + gliricidia @ 1.5 t ha^{-1} (F5) recorded the highest MBC of 361.6 µg g^{-1} soil followed by application of 25% RDF + FYM @ 2.5 t ha^{-1} (F4) while the least was recorded under absolute control (182.9 µg g^{-1} soil). Labile carbon was also significantly influenced by the treatments. It was found to be highest under gliricidia applied @ 3 t ha^{-1} (280.3 µg g^{-1} soil) and was at par with FYM @ 5 t ha^{-1} (262.9 µg g^{-1} soil) while the lowest amount was observed under absolute control (217.4 µg g^{-1} soil).

Among the physical soil quality indicators, bulk density of the soil was not influenced by any of the nutrient management treatments and varied from 1.09 to 1.23 Mg m^{-3} across the treatments (Fig 21a). Mean weight diameter of the soil aggregates was significantly highest (0.32 mm) under both FYM @ 5 t ha^{-1} and 25% RDF + gliricidia @ 1.5 t ha^{-1}.

Table 19: Effect of different INM treatments on physico-chemical and chemical soil quality parameters under Cotton + Blackgram (1:1) system in Vertisol at Parbhani

SNo	Name of the treatments	pH	EC dS m^{-1}	OC g kg^{-1}	N	P	K
					Kg ha^{-1}		
1	F1: FYM@ 5 t ha^{-1}	7.71	0.17	6.50	184.5	13.2	678.0
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	7.74	0.17	6.38	206.1	16.4	744.8
3	F3: RDF	7.77	0.16	6.38	198.3	16.7	582.8
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	8.19	0.17	6.32	185.9	16.1	623.6
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	8.17	0.17	6.49	204.2	15.2	774.4
6	Control with rotation	8.16	0.14	5.74	176.6	12.7	568.3
7	Absolute control without rotation	7.86	0.15	5.74	170.6	12.5	543.1
	CD @ 0.05	0.36	NS	0.47	23.3	2.94	79.1

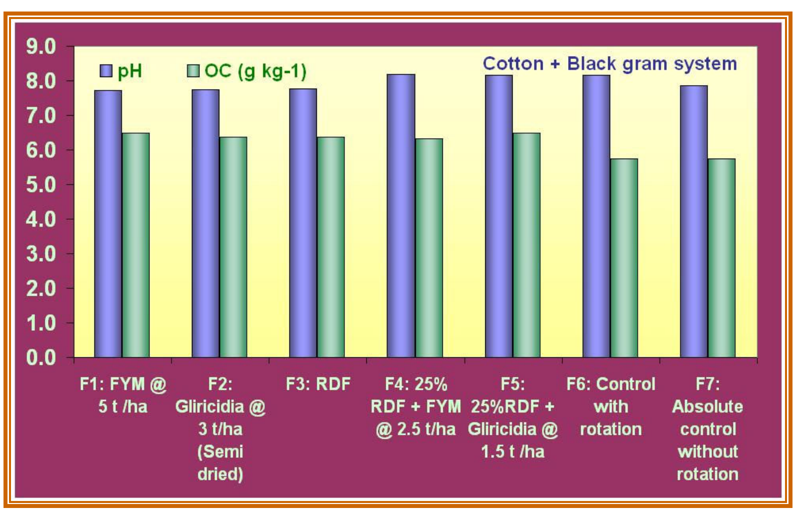


Fig 17: Effect of different INM treatments on pH and organic carbon under Cotton + Blackgram (1:1) system in Vertisol at Parbhani

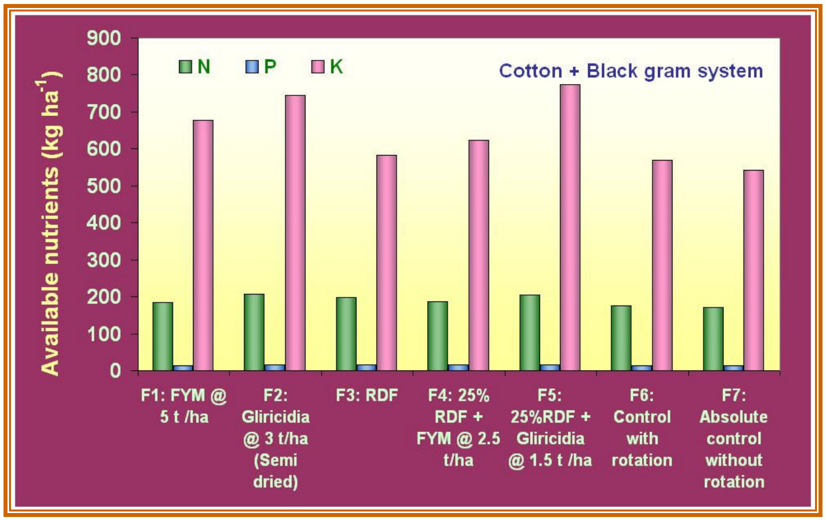


Fig 18: Effect of different INM treatments on chemical soil quality parameters (macronutrients) under Cotton + Blackgram (1:1) system in Vertisol at Parbhani

Table 20: Effect of different INM treatments on chemical soil quality parameters (secondary and micronutrients) under Cotton + Blackgram (1:1) system in Vertisol at Parbhani

SNo	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		C mol kg^{-1}		(kg ha^{-1})	µg g^{-1} soil				
1	F1: FYM@ 5 t ha^{-1}	6.23	5.21	19.0	0.25	11.2	1.42	21.0	1.21
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	6.26	4.76	14.3	0.25	11.2	1.42	22.9	1.17
3	F3: RDF	6.26	5.23	13.9	0.27	10.7	1.49	22.2	1.13
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	6.38	5.20	15.6	0.25	10.3	1.47	22.7	1.15
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	6.43	4.91	14.4	0.28	10.6	1.47	23.5	1.14
6	Control with rotation	6.09	4.60	18.1	0.23	9.4	1.34	18.8	1.10
7	Absolute control without rotation	6.19	4.66	13.5	0.25	8.7	1.33	18.6	1.04
	CD @ 0.05	NS	NS	3.56	NS	NS	NS	3.02	NS

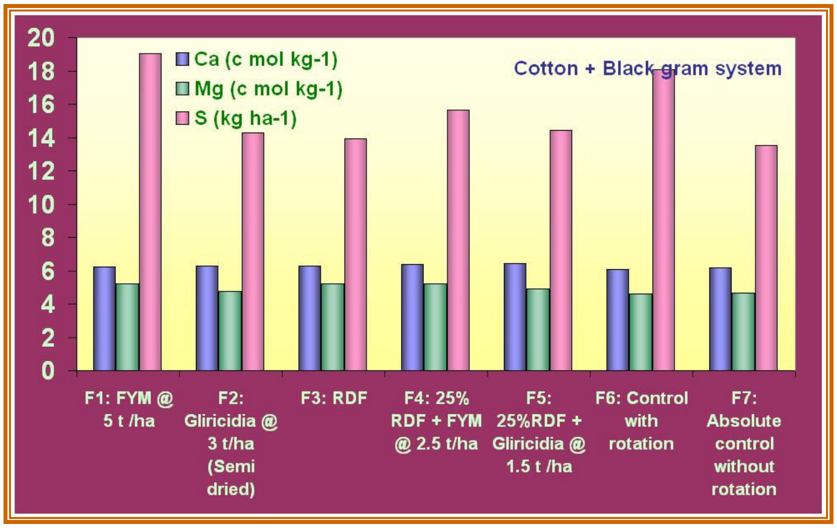


Fig 19: Effect of different INM treatments on chemical soil quality parameters (secondary nutrients) under Cotton + Blackgram (1:1) system in Vertisol at Parbhani

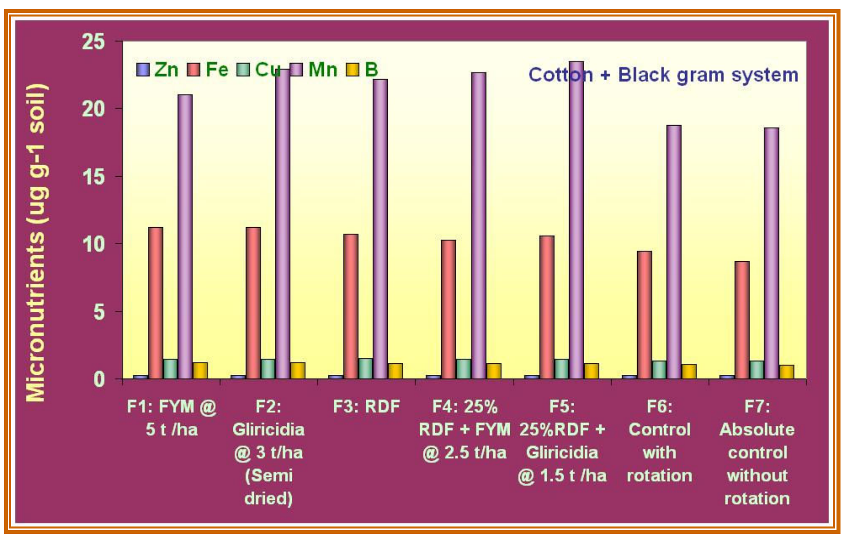


Fig 20: Effect of different INM treatments on chemical soil quality parameters (micronutrients) under Cotton + Blackgram (1:1) system in Vertisol at Parbhani

Table 21: Effect of different INM treatments on biological and physical soil quality parameters under Cotton + Blackgram (1:1) system in Vertisol at Parbhani

SNo	Name of the treatments	DHA (µg TPF g^{-1} soil hr^{-1})	MBC (µg g^{-1} soil)	LC (µg g^{-1} soil)	BD (Mg m^{-3})	MWD (mm)
1	F1: FYM@ 5 t ha^{-1}	2.12	266.0	262.9	1.09	0.32
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	2.15	231.8	280.3	1.18	0.29
3	F3: RDF	2.26	203.7	241.4	1.16	0.34
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	2.58	327.0	258.1	1.10	0.32
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	2.15	361.6	259.3	1.10	0.29
6	Control with rotation	1.71	191.0	225.7	1.22	0.26
7	Absolute control without rotation	1.59	182.9	217.4	1.23	0.25
	CD @ 0.05	0.24	29.3	24.18	NS	0.04

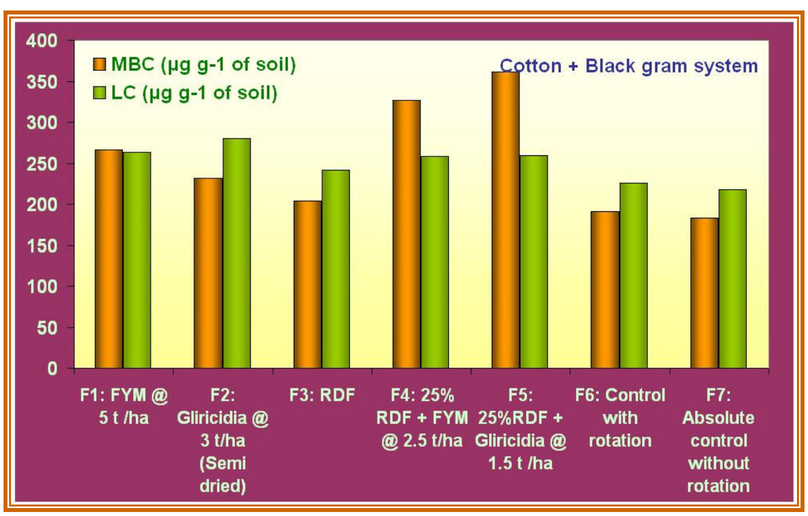


Fig 21: Effect of different INM treatments on biological soil quality parameters under Cotton + Blackgram (1:1) system in Vertisol at Parbhani

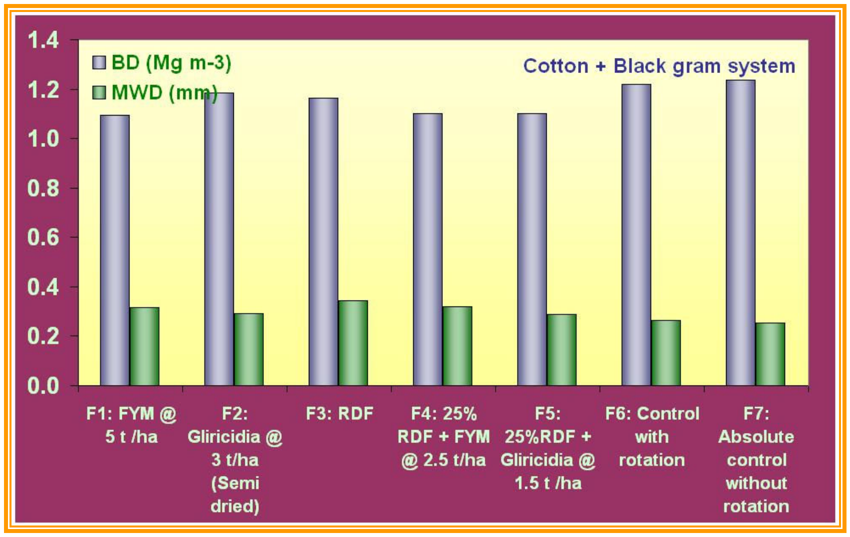


Fig 21a: Effect of different INM treatments on physical soil quality parameters under Cotton + Blackgram (1:1) system in Vertisol at Parbhani

4.2.7.1. Key indicators and soil quality assessment

4.2.7.2. Results of principal component analysis

The long-term influence of INM treatments practiced under Cotton + Blackgram (1:1) system on 19 soil quality indices has been statistically analyzed and it was observed that out of 19 soil quality parameters, eight variables were insignificant and hence, these were dropped from the further PCA analysis. In the PCA of 11 variables, four PCs had eigen values >1 and explained 81.8% variance in the data set (Table 22). In PC1, four variables were highly weighted variables viz., organic carbon, available Mn, dehydrogenase assay and labile carbon. Correlation analysis run between the highly weighted variables under PC1 (Table 23) revealed significant correlations but did not reach the set criteria (r = 0.70), except DHA with organic carbon (0.702**) and hence, all the variables have been retained for the MDS. In PC2 and PC3, the sole highly weighted variables were available S and pH respectively and had to be retained for the MDS. While in PC4, two variables viz., available K and mean weight diameter were the highly weighted variables, which revealed an insignificant correlation between them and hence were retained for the final MDS. On the whole, the variables which were retained for the final MDS included pH, organic carbon, available K, available S, available Mn, dehydrogenase assay, labile carbon and mean weight diameter and were termed as the key indicators for Cotton + Blackgram (1:1) system and these indicators were used for computing the soil quality indices.

Table 22: Principal component analysis of soil quality parameters as influenced by different INM treatments under Cotton + Blackgram (1:1) system in Vertisol at Parbhani

	PC1	PC2	PC3	PC4
Total Eigen values	5.149	1.517	1.198	1.134
% of Variance	46.810	13.793	10.891	10.310
Cumulative %	46.810	60.603	71.494	81.805
Eigen Vectors				
pH	0.061	0.372	**0.807**	0.362
OC	**0.875**	0.021	-0.184	0.107
N	0.762	-0.436	0.078	-0.264
P	0.712	-0.484	0.130	0.177
K	0.638	0.314	-0.027	**-0.583**
S	-0.195	**0.764**	-0.393	0.019
Mn	**0.801**	0.154	0.000	-0.108
DHA	**0.825**	0.006	-0.014	0.380
MBC	0.707	0.479	0.354	-0.095
LC	**0.813**	0.052	-0.082	-0.216
MWD	0.604	0.125	-0.449	**0.582**

Table 23: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs				
PC1	**OC**	**Mn**	**DHA**	**LC**
OC	1.00	0.582**	0.702**	0.695**
Mn	0.582**	1.00	0.534*	0.589**
DHA	0.702**	0.534*	1.00	0.613**
LC	0.695**	0.589**	0.613**	1.00
Correlation sum	**2.979**	**2.705**	**2.849**	**2.897**
PC2	**K**	**MWD**		
OC	1.00	0.144		
S	0.144	1.00		
Correlation sum	**1.144**	**1.144**		

4.2.7.3. Soil quality indices

Soil quality indices were computed using eight key soil quality indicators viz., pH, organic carbon, available K, available S, available Mn, dehydrogenase assay, labile carbon and mean weight diameter. The soil quality indices varied from 2.07 to 2.49 across the INM treatments (Table 24 & Fig 22). Significantly highest soil quality indices was observed with application of 25% RDF +

FYM@ 2.5 t ha^{-1} (2.54) as well as Gliricidia @ 3 t ha^{-1} (semi dried) (2.51) which was at par with other treatments also. The relative order of performance of treatments in terms of influencing soil quality, irrespective of their statistical significance was: F4: 25% RDF + FYM@ 2.5 t ha^{-1} (2.54) > F2: Gliricidia @ 3 t ha^{-1} (semi dried) (2.51) > F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1} (2.49) > F3: RDF (2.43) F1: FYM@ 5 t ha^{-1} (2.48) > Control with rotation (2.15) > Absolute control without rotation (2.07). The soil quality indices when reduced to a scale of 1.00 varied from 0.78 to 0.96 across the INM treatments. The percent contributions of key indicators towards soil quality indices were: pH (5%), organic carbon (21%), available K (4%), available S (5%), available Mn (21%), dehydrogenase assay (19%), labile carbon (20%) and mean weight diameter (5%) (Fig 23).

Table 24: Soil quality indices as influenced by different INM treatments under Cotton + Blackgram (1:1) system in Vertisol at Parbhani

SNo	Name of the treatments	SQI	RSQI
1	F1: FYM@ 5 t ha^{-1}	2.48	0.94
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	2.51	0.95
3	F3: RDF	2.43	0.92
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	2.54	0.96
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	2.49	0.94
6	Control with rotation	2.15	0.82
7	Absolute control without rotation	2.07	0.78
	CD @ 0.05	0.09	0.04

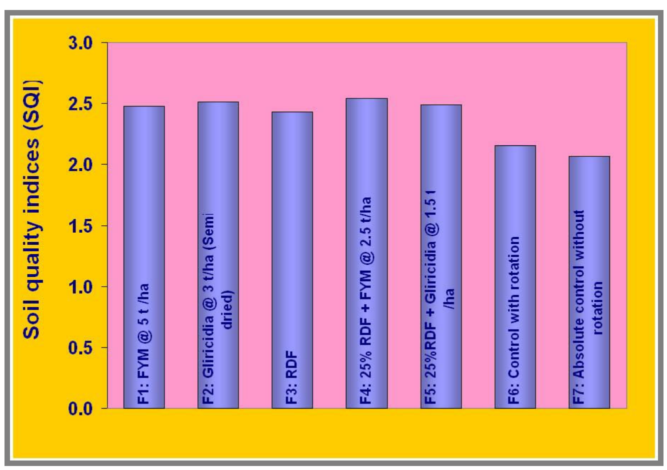


Fig 22: Soil quality indices as influenced by different INM treatments under Cotton + Blackgram (1:1) system in Vertisol at Parbhani

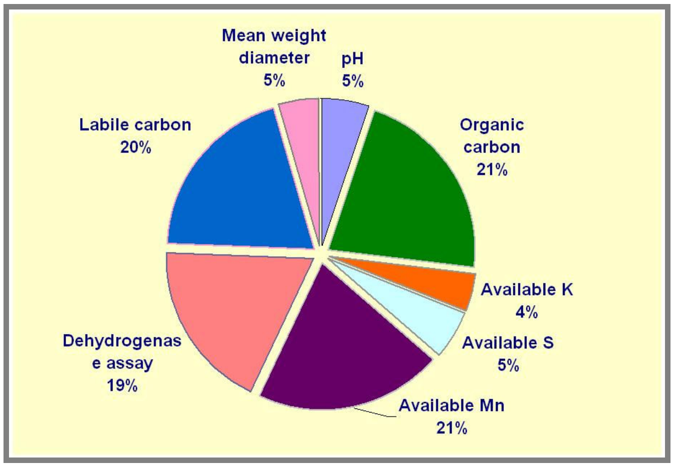


Fig 23: Percent contribution of key indicators towards soil quality indices as influenced by different INM treatments under Cotton + Blackgram (1:1) system in Vertisol at Parbhani

4.2.8 Mung bean + rabi sorghum system

The data obtained on soil quality parameters under mung bean – rabi sorghum system are presented in Tables 25 to 27.

The soil reaction under mung bean + rabi sorghum system was slightly alkaline with pH values varying from 8.05 to 8.31 and were not significantly influenced by the INM treatments (Fig 24). Electrical conductivity of the soils was also not affected by the INM treatments and ranged between 0.15 to 0.19 dS m^{-1}.

Despite the conjunctive use of organics and inorganics, the predominant soil quality parameters such as organic carbon as well as available nitrogen were not significantly influenced. Their contents varied from 5.69 to 6.37 g kg^{-1} and 187.3 to 228.1 kg ha^{-1} respectively. Whereas available P content was significantly influenced by the INM treatments, and application of 25% RDF + gliricidia @ 1.5 t ha^{-1} (F5) recorded the highest available P of 19.0 kg ha^{-1} while the lowest amount (12.8 kg ha^{-1}) was observed under absolute control without rotation (F7). Available soil K content varied between 534.5 to 771.7 kg ha^{-1}. The highest available K content of 771.7 kg ha^{-1} was observed with FYM applied @ 5 t ha^{-1} and was at par with 25% RDF + gliricidia @ 1.5 t ha^{-1} (716.3 kg ha^{-1}). The next best combination which maintained higher amount of available K was 25% RDF + FYM @ 2.5 t ha^{-1} (654.6 kg ha^{-1}) (Fig 25). As in case of above 3 cropping systems, in this system also, exchangeable Ca and Mg were not significantly influenced by the nutrient management treatments. However, exchangeable Ca and Mg varied between 5.93 to 6.47 and 4.46

to 5.20 c mol kg^{-1} soil. The available S was found to be significantly highest under application of 25% RDF + gliricidia @ 1.5 t ha^{-1} (F5) (26.5 kg ha^{-1}) which was at par with application of 25% RDF + FYM @ 2.5 t ha^{-1} (F4), while gliricidia applied @ 3t ha^{-1} (semi dried) (F2) recorded the lowest content of available S (13.8 kg ha^{-1}) (Fig 26).

The micronutrients viz., Zn and Cu were not significantly influenced by the INM treatments and ranged from 0.25 to 0.32 and 1.38 to 1.45 µg g^{-1} soil (Fig 27). Available Mn was found to be significantly highest in application of recommended dose of fertilizer (RDF) (F3) (23.3 µg g^{-1} soil) which was at par with other treatments, while the lowest was observed under control with rotation (F6) (18.9 µg g^{-1} soil). Available B in the soils varied from 0.73 to 1.23 µg g^{-1} soil and was found to be significantly influenced by the treatments.

The biological soil quality parameters were significantly influenced by the INM treatments. Dehydrogenase activity was found to be highest under application of 25% RDF + FYM @ 2.5 t ha^{-1} (F4) (2.39 µg TPF g^{-1} soil hr^{-1}) which was at par with application of 25% RDF + gliricidia @ 1.5 t ha^{-1} (F5) and application of recommended dose of fertilizer (RDF) (F3) while, the lowest was observed under absolute control without rotation (F7). But, MBC was found to be significantly highest under FYM@ 5 t ha^{-1} (294.7 µg g^{-1} soil) which was at par with gliricidia applied @ 3t ha^{-1} (semi dried) (F2) and the lowest content was observed under absolute control without rotation (F7) (152.4 µg g^{-1} soil). Labile carbon in the soils was found to be significantly highest under 25% RDF + FYM @ 2.5 t ha^{-1} (276.4 µg g^{-1} soil) which was at par with FYM @ 5 t ha^{-1} (274.8 µg g^{-1} soil). This was followed by gliricidia @ 3 t ha^{-1} (258.8 µg g^{-1} soil) while the lowest amount was recorded under control plots (Fig 28).

Among the physical soil quality indicators, only MWD was significantly influenced by the nutrient management treatments. However, there was no influence on BD. Application of sole organic treatments viz., gliricidia @ 3 t ha^{-1} and FYM @ 5 t ha^{-1} significantly improved the MWD to the extent of 0.37 mm and 0.32 mm respectively (Fig 29).

Table 25: Effect of different INM treatments on soil quality parameters under mung bean + rabi sorghum system in Vertisol at Parbhani

SNo	Name of the treatments	pH	EC dS m^{-1}	OC g kg^{-1}	N	P	K
					kg ha^{-1}		
1	F1: FYM@ 5 t ha^{-1}	8.07	0.19	5.70	214.0	14.9	771.7
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	8.18	0.17	6.06	228.1	14.4	609.5
3	F3: RDF	8.31	0.19	6.23	210.6	15.1	647.9
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	8.05	0.18	6.37	210.9	18.0	654.6
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	8.14	0.18	6.24	207.9	19.0	716.3
6	Control with rotation	8.09	0.15	5.88	197.6	13.8	569.7
7	Absolute control without rotation	8.15	0.18	5.69	187.3	12.8	534.5
	CD @ 0.05	NS	NS	NS	NS	3.22	95.9

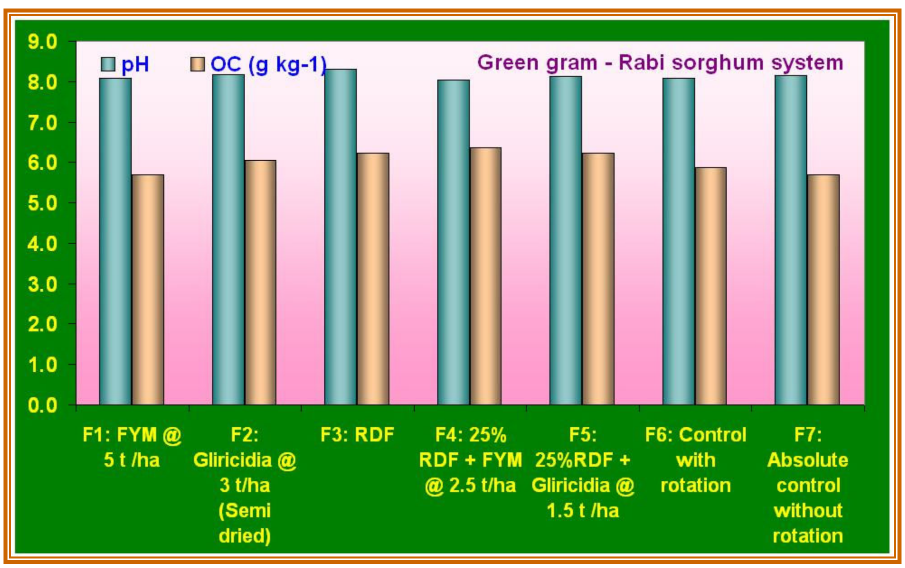


Fig 24: Effect of different INM treatments on pH and organic carbon under mung bean + rabi sorghum system in Vertisol at Parbhani

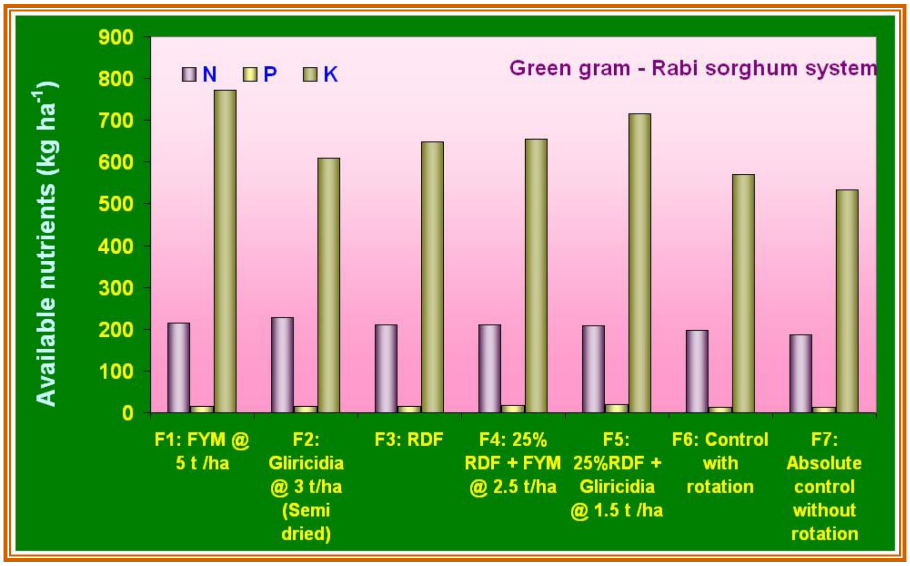


Fig 25: Effect of different INM treatments on chemical soil quality parameters (macronutrients) under mung bean + rabi sorghum system in Vertisol at Parbhani

Table 26: Effect of different INM treatments on chemical soil quality parameters (secondary and micronutrients) under mung bean + rabi sorghum system in Vertisol at Parbhani

SNo	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		Cmol kg^{-1}		(kg ha^{-1})	µg g^{-1} of soil				
1	F1: FYM@ 5 t ha^{-1}	6.23	5.08	15.4	0.29	11.3	1.44	22.6	1.20
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	6.03	4.75	13.8	0.32	11.2	1.45	22.9	1.18
3	F3: RDF	6.17	5.12	17.6	0.29	11.6	1.44	23.3	1.22
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	6.34	5.20	22.1	0.31	9.8	1.44	21.3	1.13
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	6.47	5.11	26.5	0.28	9.6	1.42	21.0	1.16
6	Control with rotation	6.11	4.49	17.1	0.29	8.2	1.41	18.9	1.23
7	Absolute control without rotation	5.93	4.46	17.8	0.25	8.7	1.38	19.4	0.73
	CD @ 0.05	NS	NS	4.03	NS	1.97	NS	2.27	0.21

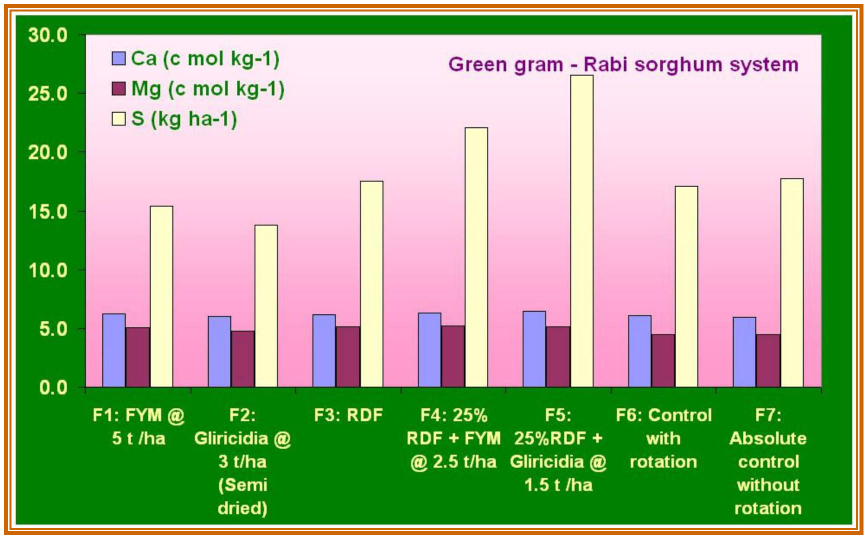


Fig 26: Effect of different INM treatments on chemical soil quality parameters (secondary nutrients) under mung bean + rabi sorghum system in Vertisol at Parbhani

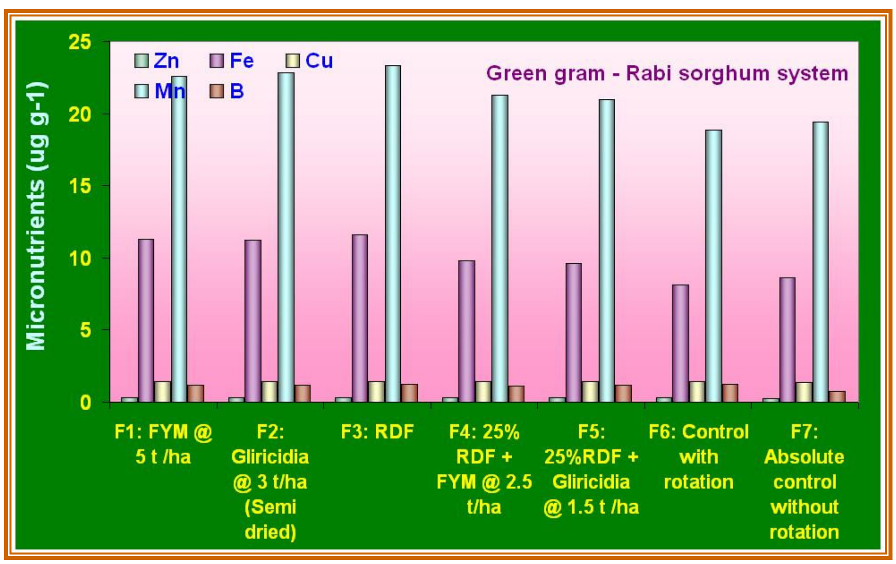


Fig 27: Effect of different INM treatments on chemical soil quality parameters (micronutrients) under mung bean + rabi sorghum system in Vertisol at Parbhani

Table 27: Effect of different INM treatments on biological and physical soil quality parameters under mung bean + rabi sorghum system in Vertisol at Parbhani

SNo	Name of the treatments	DHA (µg TPF g^{-1} soil hr^{-1})	MBC (µg g^{-1} soil)	LC (µg g^{-1} soil)	BD (Mg m^{-3})	MWD (mm)
1	F1: FYM@ 5 t ha^{-1}	2.06	294.7	274.8	1.20	0.32
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	1.68	273.4	258.8	1.20	0.37
3	F3: RDF	2.23	212.1	227.9	1.21	0.28
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	2.39	248.7	276.4	1.21	0.29
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	2.36	235.2	250.6	1.21	0.28
6	Control with rotation	1.56	184.7	216.4	1.27	0.25
7	Absolute control without rotation	1.45	152.4	214.3	1.25	0.27
	CD @ 0.05	0.29	31.21	35.0	NS	0.06

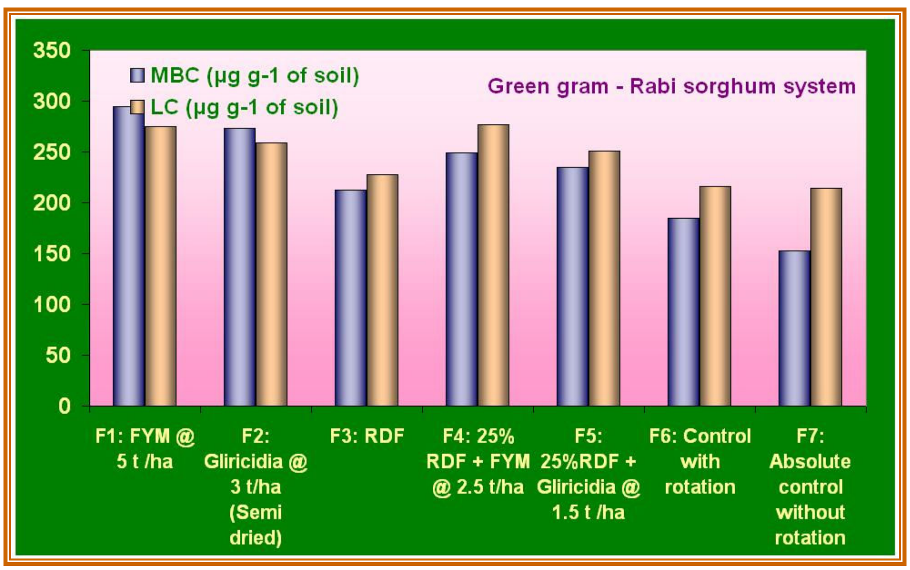


Fig 28: Effect of different INM treatments on biological soil quality parameters under mung bean + rabi sorghum system in Vertisol at Parbhani

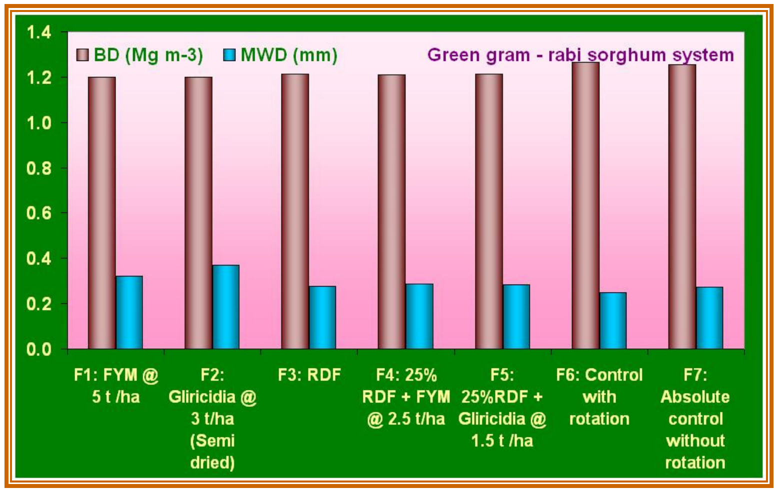


Fig 29: Effect of different INM treatments on physical soil quality parameters under mung bean + rabi sorghum system in Vertisol at Parbhani

4.2.8.1. Key indicators and soil quality assessment

4.2.8.2. Results of principal component analysis

The long-term influence of INM treatments practiced under mung bean + rabi sorghum system on 19 soil quality indices has been statistically analyzed and it was observed that out of 19 soil quality parameters, nine variables were insignificant and hence, these were dropped and the PCA analysis was carried out with only ten variables. In the PCA of 10 variables, only two PCs had eigen values >1 and explained 68.5% variance in the data set (Table 28). In PC1 the highly weighted variables were available K, available Mn, microbial biomass carbon and labile carbon, while in PC2, only one variable viz., available S was the highly weighted variable. Correlation analysis run between the four variables qualified under PC1 (Table 29) revealed that MBC as well as LC had significant good correlation between them and only one could be retained. But having the highest correlation sums of 2.97 for MBC and 2.93 for LC, both were retained as only very few indicators have been qualified. On the other hand, available K as well as available Mn had to be retained for the MDS as they had no significant correlation between them. On the whole, all the five highly weighted indicators viz., available K, available S, available Mn, microbial biomass carbon as well as labile carbon were retained for the final MDS and termed as the key indicators for mung bean + rabi sorghum system in Vertisol at Parbhani and these indicators were used for computing the soil quality indices.

Table 28: Principal component analysis of soil quality parameters as influenced by different INM treatments under mung bean + rabi sorghum system in Vertisol at Parbhani

	PC1	PC2
Total Eigen values	4.594	2.255
% of Variance	45.941	22.553
Cumulative %	45.941	68.495
Eigen Vectors		
P	0.544	0.611
K	**0.785**	0.258
S	0.181	**0.876**
Fe	0.738	-0.328
Mn	**0.766**	-0.391
B	0.551	0.003
DHA	0.741	0.561
MBC	**0.849**	-0.227
LC	**0.813**	-0.035
MWD	0.535	-0.648

Table 29: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs				
PC1	**K**	**Mn**	**MBC**	**LC**
K	1.00	0.408	0.638**	0.636**
Mn	0.408	1.00	0.551**	0.504*
MBC	0.638**	0.551**	1.00	0.785**
LC	0.636**	0.504*	0.785**	1.00
Correlation sum	**2.682**	**2.463**	**2.974**	**2.925**

4.2.8.3. Soil quality indices

Soil quality indices were computed using five key soil quality indicators viz., available K, available S, available Mn, microbial biomass carbon as well as labile carbon. The soil quality indices varied from 2.00 to 2.70 across the INM treatments 9Table 30 & Fig 30). Among all the INM treatments, significantly highest soil quality index was observed with application of FYM@ 5 t ha^{-1} (2.70) which was at par with application of 25% RDF + FYM@ 2.5 t ha^{-1} as well as 25% RDF + FYM@ 2.5 t ha^{-1} each having an SQI of 2.55 followed by Gliricidia @ 3 t ha^{-1} (semi dried). It was observed that the treatments, which received FYM, showed the highest soil quality followed by the treatments, which received gliricidia component. Irrespective of their statistical significance, the relative order of performance of treatments in terms of influencing soil quality were: F1: FYM@ 5 t ha^{-1} (2.70) > F4: 25% RDF + FYM@ 2.5 t ha^{-1} (2.55) = F5: 25% RDF +

Gliricidia @ 1.5 t ha^{-1} (2.55) > F2: Gliricidia @ 3 t ha^{-1} (semi dried) (2.47) > F3: RDF (2.36) > Control with rotation (2.08) > Absolute control without rotation (2.00). The soil quality indices when reduced to a scale of 1.00 varied from 0.66 to 0.99 across the INM treatments. The percent contributions of key indicators towards soil quality indices were: available K (23%), available S (9%), available Mn (23%), microbial biomass carbon (21%) as well as labile carbon (24%) (Fig 31).

Table 30: Soil quality indices as influenced by different INM treatments under mung bean + rabi sorghum system in Vertisol at Parbhani

SNo	Name of the treatments	SQI	RSQI
1	F1: FYM@ 5 t ha^{-1}	2.70	0.99
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	2.47	0.90
3	F3: RDF	2.36	0.86
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	2.55	0.93
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	2.55	0.93
6	Control with rotation	2.08	0.76
7	Absolute control without rotation	2.00	0.73
	CD @ 0.05	0.21	0.08

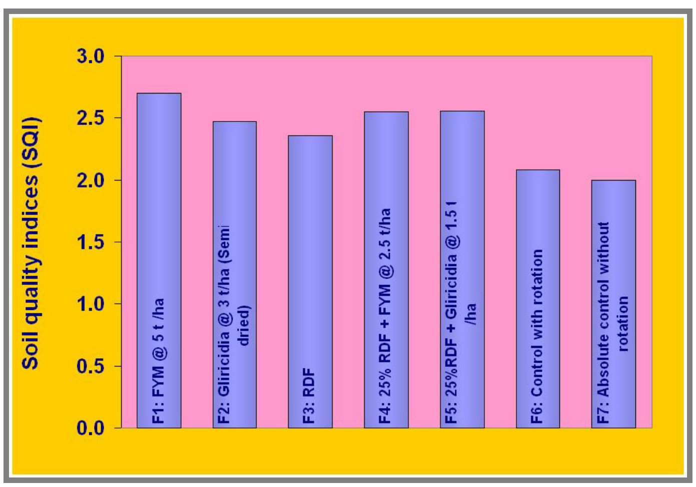


Fig 30: Soil quality indices as influenced by different INM treatments under mung bean + rabi sorghum system in Vertisol at Parbhani

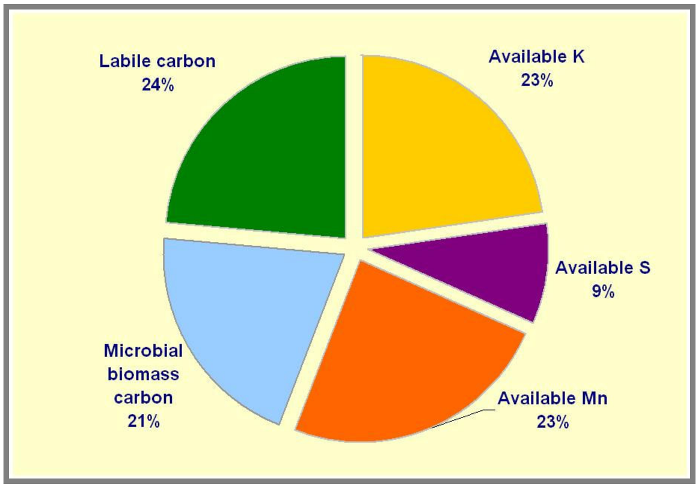


Fig 31: Percent contribution of key soil quality indicators towards soil quality indices as influenced by different INM treatments under mung bean + rabi sorghum system in Vertisol at Parbhani

Table 31: Summary of soil quality indices and relative soil quality indices as influenced by different soil nutrient management practices under different trials practiced in Vertisols of Parbhani

Sno		SQI	RSQI
Experiment 1: Organic farming comprising of INM treatments and legume based cropping systems			
Sorghum + Pigeon pea (4:2) system			
1	F1: FYM@ 5 t ha^{-1}	2.47	0.97
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	2.30	0.90
3	F3: RDF	2.27	0.89
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	2.43	0.96
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	2.31	0.90
6	Control with rotation	1.75	0.69
7	Absolute control without rotation	1.68	0.66
	CD @ 0.05		
Soybean + Pigeon pea (4:2) system			
1	F1: FYM@ 5 t ha^{-1}	2.16	0.99
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	2.00	0.92
3	F3: RDF	1.79	0.82

Sno		SQI	RSQI
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	1.90	0.87
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	1.97	0.90
6	Control with rotation	1.60	0.74
7	Absolute control without rotation	1.48	0.68
	CD @ 0.05		
Cotton + Black gram (1:1) system			
1	F1: FYM@ 5 t ha^{-1}	2.48	0.94
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	2.51	0.95
3	F3: RDF	2.43	0.92
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	2.54	0.96
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	2.49	0.94
6	Control with rotation	2.15	0.82
7	Absolute control without rotation	2.07	0.78
	CD @ 0.05		
Mung bean + Rabi sorghum system			
1	F1: FYM@ 5 t ha^{-1}	2.70	0.98
2	F2: Gliricidia @ 3 t ha^{-1} (semi dried)	2.47	0.90
3	F3: RDF	2.36	0.86
4	F4: 25% RDF + FYM@ 2.5 t ha^{-1}	2.55	0.93
5	F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1}	2.55	0.93
6	Control with rotation	2.08	0.76
7	Absolute control without rotation	2.00	0.73
	CD @ 0.05		

Table 32: Summary of key soil quality indicators, soil quality indices and the best soil nutrient management practices identified from the view point of soil quality improvement under different cropping systems in Vertisols of Parbhani

Sno	Key soil quality indicators and their % contribution	SQI	RSQI	Best management practices with higher SQI
Experiment 1: Organic farming comprising of INM treatments and legume based cropping systems				
Sorghum + Pigeon pea (4:2) system				
1	• Mean weight diameter (29%) • Labile carbon (28%) • Dehydrogenase assay (26%) • Organic carbon (10%) • Available S (7%)	1.68-2.47	0.66 – 0.97	1. Application of FYM@ 5 t ha^{-1} (2.47) 2. Application of 25% RDF + FYM@ 2.5 t ha^{-1} (2.43) 3. Application of 25% RDF + Gliricidia @ 1.5 t ha^{-1} (2.31)
Soybean + Pigeon pea (4:2) system				
2	• pH (7%) • Available S (8%) • Dehydrogenase assay (29%) • Labile carbon (31%) • Mean weight diameter (25%)	1.48-2.16	0.68 - 0.99	1. Application of FYM@ 5 t ha^{-1} (2.16) 2. Application of Gliricidia @ 3 t ha^{-1} (semi dried) (2.00) 3. Application of 25% RDF + Gliricidia @ 1.5 t ha^{-1} (1.97) 4.
Cotton + Black gram (1:1) system				
3	• pH (5%) • Organic carbon (21%) • Available K (4%) • Available S (5%) • Available Mn (21%) • Dehydrogenase assay (19%) • Labile carbon (20%) • Mean weight diameter (5%)	2.07 – 2.54	0.78 – 0.96	1. Application of 25% RDF + FYM@ 2.5 t ha^{-1} (2.54) 2. Application of Gliricidia @ 3 t ha^{-1} (semi dried) (2.51) 3. Application of 25% RDF + Gliricidia @ 1.5 t ha^{-1} (2.49)
Mung bean + Rabi sorghum system				
4	• Available K (23%) • Available S (9%) • Available Mn (23%) • Microbial biomass carbon (21%) • Labile carbon (24%)	2.00 – 2.70	0.73 – 0.98	1. Application of FYM@ 5 t ha^{-1} (2.70) 2. Application of 25% RDF + FYM@ 2.5 t ha^{-1} (2.55) 3. Application of 25% RDF + Gliricidia @ 1.5 t ha^{-1} (2.55)

Sardar Krishi Nagar, Dantiwada Centre

Pearl millet based production system

4.2.9. Effect of predominant soil and nutrient management practices on soil quality indicators (attributes) and soil quality indices at SK Nagar, Dantiwada centre of AICRPDA

Location description, climate and soil characteristics

Dantiwada dryland centre is located in Gujarat state. It represents western plain, Kachchh and part of Kathiawar peninsula, hot arid ecoregion; Rajasthan bagar north Gujarat plain, and south – western Punjab plain, hot typic-arid eco-subregion. Soils belong to Aridisol order and are deep, loamy desert, which includes saline phase, with low available water capacity. Length of growing period varies from 60- 90 days. Soils have been susceptible to water erosion, with moderate loss of topsoil, affecting 11-25% area. Medium severity, wind erosion with moderate loss of topsoil, affecting 26-50% area, high severity and moderate chemical deterioration due to salinization, affecting 11-25% area. Potential evapotranspiration is to the tune of 572 mm with 844 mm rainfall, near normal soil reaction, suitable electrical conductivity, low organic carbon, nearing medium to high phosphate availability.

In order to study the effect of predominant soil and nutrient management practices on soil quality indicators, and the soil quality indices, the following experiment was chosen at Dantiwada centre.

- Experiment 1: Long-term manurial trial

4.2.10. Experiment 1: Long-term manurial trial

A long-term manurial trial was initiated during the year 1989 and continued upto 2006 at AICRP for dryland agriculture, Regional Research Station, Dantiwada Agricultural University, Sardar Krishinagar, Dantiwada. Soil quality assessment studies were taken up in this experiment during the year 2005 in order to identify the key soil indicators as well as to identify the best management practice for this cropping system. The experiment was laid out in a randomized block design with six nutrient management treatments in three replications using pearl millet as test crop. The different nutrient management combinations included in the study comprised of T1 = Control, T2 = 100 % RDN through urea, T3 = 50 % RDN through urea, T4 = 50 % RDN through FYM, T5 =

50 % RDN (urea) + 50% RDN (FYM) and T6 = Farmers method 5 t FYM ha^{-1} (once in three years).

In this experiment the soil quality assessment studies were undertaken after 17 years of experimentation and the complete data set on 19 soil parameters is presented in Tables 33 to 35 & Fig 32 to 35.

The data reveals that the soil reaction in the experimental plot was near neutral across the treatments with the pH varying from 7.61 to 7.91. Available nitrogen in the soils was very low and ranged from 76.4 to 104.7 kg ha^{-1}. When compared to control, application of 100% recommended dose of nitrogen through urea and 50% N through urea + 50% N through FYM recorded 104. 67 kg ha^{-1} and 101.61 kg ha^{-1} of available N respectively. Available P in the soils ranged from 18.6 to 26.6 kg ha^{-1} and the highest P (26.55 kg ha^{-1}) was recorded in 50 % RDN (urea) + 50% RDN (FYM). Application of 50 % RDN through urea showed an available K of 148.3 kg ha^{-1} while, significant higher potassium in soil was recorded in 50 % RDN (urea) + 50% RDN (FYM) (256.2 kg ha^{-1}). Exchangeable calcium and magnesium in the soil ranged from 3.62 to 4.88 and 0.49 to 0.74 cmol kg^{-1} respectively. Farmer's method, which received 5 t FYM ha^{-1} once in three years, recorded highest available sulphur (14.8 µg g^{-1}) when compared to the control (11.3 µg g^{-1}). DTPA extractable zinc was significantly highest in the treatment which received 100% RDN through urea (1.19 µg g^{-1}) followed by 50% RDN through urea (1.17µg g^{-1}). Farmer's method, which received 5t FYM ha^{-1} once in three years, recorded 5.36µg g^{-1} of DTPA extractable iron in the soils. Manganese in the soil ranged from 4.17 to 5.24 µg g^{-1} while boron was in the range of 0.31 to 0.44 µg g^{-1}.

Dehydrogenase assay in the soils was highest in farmer's method which received 5 t FYM ha^{-1} once in three years (3.59 µg TPF $hr^{-1}g^{-1}$ followed by 50% RDN through FYM (3.54 µg TPF $hr^{-1}g^{-1}$). Microbial biomass carbon in the soils was recorded very low as the analysis was carried out in freezer stored samples. However, 50 % RDN (urea) + 50% RDN (FYM) recorded the highest microbial biomass carbon 67.00 µg g^{-1} of soil followed by 50 % RDN through FYM (66.19 µg g^{-1} of soil). Labile carbon was significantly highest under 50 % RDN (urea) + 50% RDN (FYM) (243.0 µg g^{-1} of soil) and was at par with 50 % RDN through FYM (234.5 µg g^{-1} of soil), while the control plot recorded the least (141.7 µg g^{-1} of soil). The bulk density of the soil ranged from 1.51 to 1.64 Mg m^{-3} while the mean weight diameter varied from 0.14 to 0.26 mm across the treatments. The data set thus generated through series of laboratory analysis was subjected to statistical analysis for testing the levels of significance. Among the 19 soil parameters, only pH and Cu were not significantly influenced by the management treatments.

Table 33: Effect of long-term manurial treatments on soil chemical parameters under pearl millet in Aridisols of Dantiwada

SNo	Name of the treatments	pH	EC (dS m^{-1})	OC (g kg^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
1	T1 = Control	7.91	0.18	1.82	76.4	18.6	183.2
2	T2 = 100 % RDN through urea	7.81	0.16	2.42	104.7	20.9	148.3
3	T3 = 50 % RDN through urea	7.80	0.14	1.93	94.6	20.8	150.1
4	T4 = 50 % RDN through FYM	7.72	0.20	2.86	90.3	25.6	240.7
5	T5 = 50 % RDN (urea) + 50% RDN (FYM)	7.61	0.19	2.94	101.6	26.6	256.6
6	T6 = Farmers method 5 t FYM ha^{-1} (once in three years)	7.81	0.21	2.83	88.1	20.6	218.6
	CD @ 0.05	NS	0.03	0.17	8.35	2.48	12.7

Table 34: Effect of long-term manurial treatments on chemical soil quality parameters under pearl millet in Aridisols of Dantiwada

SNo	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		C mol kg^{-1}		(µg g^{-1})					
1	T1 = Control	4.11	0.49	11.3	0.84	4.35	0.34	4.17	0.31
2	T2 = 100 % RDN through urea	4.44	0.67	14.2	1.19	5.25	0.34	4.31	0.47
3	T3 = 50 % RDN through urea	3.62	0.59	11.4	1.17	5.25	0.41	4.28	0.39
4	T4 = 50 % RDN through FYM	3.95	0.74	14.1	0.90	4.62	0.37	5.24	0.44
5	T5 = 50 % RDN (urea) + 50% RDN (FYM)	3.71	0.73	12.8	1.08	4.49	0.37	4.45	0.44
6	T6 = Farmers method 5 t FYM ha^{-1} (once in three years)	4.88	0.68	14.8	1.12	5.36	0.36	5.01	0.34
	CD @ 0.05	0.43	0.02	1.23	0.08	0.38	NS	0.60	0.03

Table 35: Effect of long-term manurial treatments on biological and physical soil quality parameters under pearl millet in Aridisols of Dantiwada

SNo	Name of the treatments	DHA (µg TPF hr^{-1} g^{-1} soil)	MBC (µg g^{-1} soil)	LC (µg g^{-1} soil)	BD Mg m-3)	MWD (mm)
1	T1 = Control	3.26	43.2	141.7	1.64	0.14
2	T2 = 100 % RDN through urea	3.26	57.2	159.3	1.51	0.20
3	T3 = 50 % RDN through urea	3.01	45.2	152.0	1.58	0.21
4	T4 = 50 % RDN through FYM	3.54	66.2	234.5	1.62	0.26
5	T5 = 50 % RDN (urea) + 50% RDN (FYM)	3.22	67.0	243.0	1.61	0.24
6	T6 = Farmers method 5 t FYM ha^{-1} (once in three years)	3.59	56.4	193.9	1.61	0.19
	CD @ 0.05	0.17	5.28	24.4	0.03	0.05

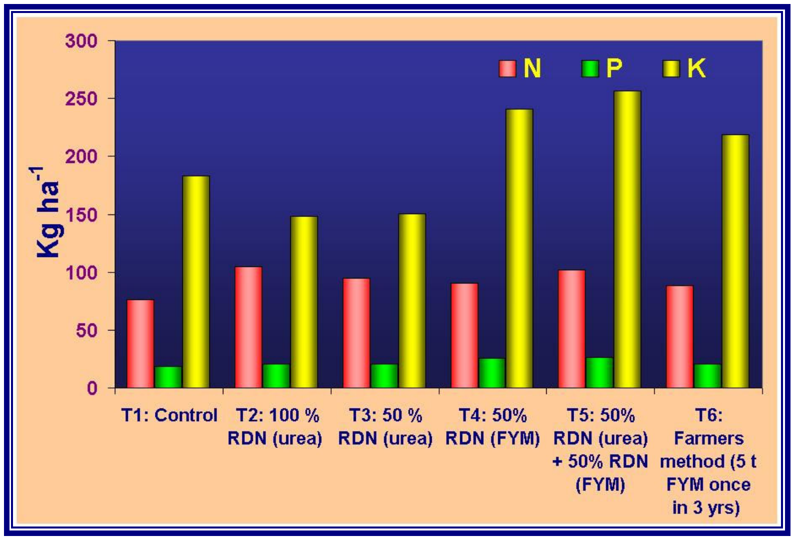


Fig 32: Effect of long-term manurial treatments on soil macronutrients under pearl millet in Aridisols of Dantiwada

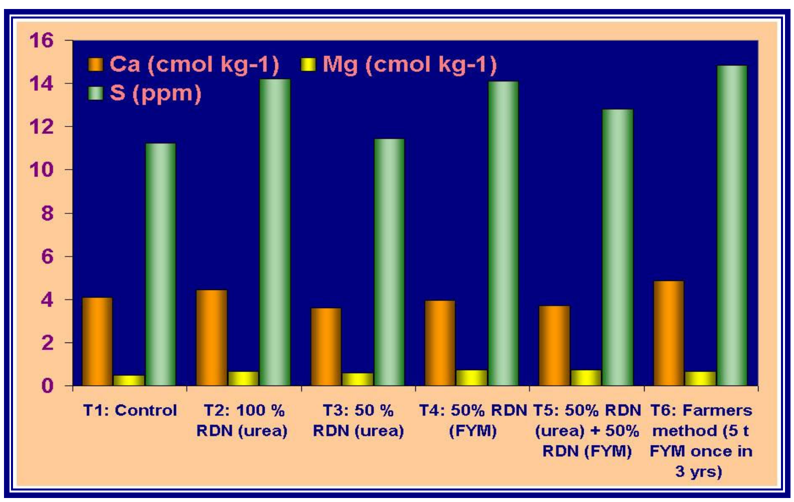


Fig 33: Effect of long-term manurial treatments on soil secondary nutrients under pearl millet in Aridisols of Dantiwada

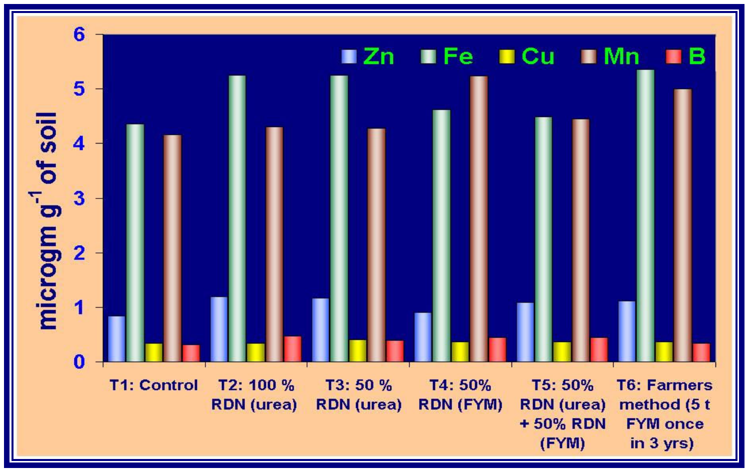


Fig 34: Effect of long-term manurial treatments on soil micronutrients under pearl millet in Aridisols of Dantiwada

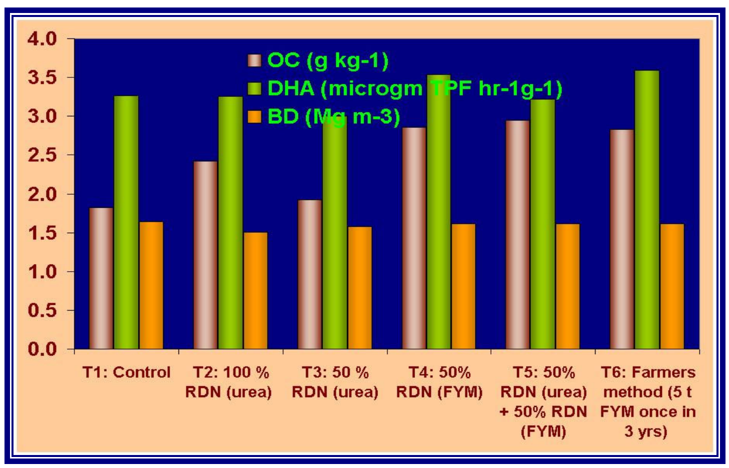


Fig 35: Effect of long-term manurial treatments on organic carbon, dehydrogenase assay and bulk density under pearl millet in Aridisols of Dantiwada

4.2.10.1. Key indicators and soil quality assessment

4.2.10.2. Results of principal component analysis

The long-term influence of manurial treatments practiced under pearl millet system on 19 soil quality indices has been studied and it was observed that out of 19 soil quality parameters, two variables viz., pH and available Cu were not significantly influenced by the management treatments and were dropped from the PCA. In the PCA of 17 variables, three PCs had eigen values >1 and explained 84.5% variance in the data set (Table 36). In PC1, organic carbon, exchangeable Mg, Microbial biomass carbon (MBC) and labile carbon (LC) were qualified as the highly weighted variables. In PC2 the variables found to be highly weighted were available N, available Zn and bulk density while in PC3, only one variable viz., exchangeable Ca was the highly weighted variable. The correlation matrix (Table 37) run for the variables qualified under PC1 revealed quite significant correlation between all the four parameters. But considering their importance, except exchangeable Mg, the other parameters were retained for the minimum data set. In PC2, among the three variables, the correlation coefficient of available Zn with available N (0.697**) was slightly below the limit set (0.70) and hence was retained for the minimum data set, while the other two parameters, i.e. available N and bulk density though had significant and well correlation also had to be retained for the minimum data set depending upon their significance and the role they play in terms of chemical and physical properties in soil. In PC2, the sole parameter highly weighted ie exchangeable Ca was however retained for the minimum data set. Hence, the final parameters retained for the minimum data set were organic carbon, available N, exchangeable Ca and Mg, available Zn, labile carbon and bulk density and were termed as the key indicators for pearl millet system under Aridisols of Dantiwada.

Table 36: Principal component analysis of soil quality parameters as influenced by different long-term manurial treatments under pearl millet system

Sno	**PC1**	**PC2**	**PC3**
Total Eigen values	7.511	4.081	2.765
% of Variance	44.182	24.006	16.267
Cumulative %	44.182	68.187	84.455
Eigen Vectors			
EC	0.655	-0.563	0.267
OC	**0.957**	0.025	0.147
N	0.400	**0.848**	-0.138
P	0.801	0.000	-0.479
K	0.792	-0.503	-0.133
Ca	0.031	-0.038	**0.916**
Mg	**0.944**	0.276	-0.018
S	0.661	0.168	0.624
Zn	0.039	**0.846**	0.200
Fe	-0.069	0.660	0.569
Mn	0.656	-0.178	0.355
B	0.551	0.640	-0.317
DHA	0.547	-0.410	0.632
MBC	**0.956**	0.093	-0.114
LC	**0.916**	-0.163	-0.218
BD	0.085	**-0.918**	-0.169
MWD	0.780	0.221	-0.314

Table 37: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs				
PC1	**OC**	**Mg**	**MBC**	**LC**
OC	1.00	0.907**	0.908**	0.872**
Mg	0.907**	1.00	0.918**	0.838**
MBC	0.908**	0.918**	1.00	0.862**
LC	0.872**	0.838**	0.962**	1.00
Correlation sum	3.687	3.663	3.788	3.572
PC2	**N**	**Zn**	**BD**	
N	1.00	0.697**	-0.712**	
Zn	0.697**	1.00	-0.707**	
BD	-0.712**	-0.707**	1.00	
Correlation sum	2.409	2.404	2.419	

*correlation is significant at P = 0.05 level
**correlation is significant at P = 0.01 level

4.2.10.3. Soil quality indices

Soil quality indices were computed using seven key soil quality indicators viz.., organic carbon, available N, exchangeable Ca and Mg, available Zn, labile carbon and bulk density. The soil quality indices varied from 1.77 to 2.46 across the long-term manurial treatments practiced for pearl millet system (Table 38 & Fig 36). For simple understanding, the soil quality indices were reduced to a scale of one, termed as 'relative soil quality indices' (RSQI), which varied between 0.71 to 0.99. Among all the manurial treatments practiced, the application of 50 % RDN (urea) + 50% RDN (FYM) showed the highest soil quality index of 2.46 followed by 50 % RDN through FYM (0.95). Irrespective of their statistical significance, the relative order of performance in influencing soil quality in terms of SQI was: T5: 50 % RDN (urea) + 50% RDN (FYM) (2.46) > T4: 50 % RDN through FYM (2.37) > T6: Farmers method 5 t FYM ha^{-1} once in three years (2.31) > T2: 100 % RDN through urea (2.23) > T3: 50 % RDN through urea (2.00) > T1: Control (1.77). The average percent contribution of key indicators towards soil quality indices was: organic carbon (19.9%), available N (11.3%), exchangeable Ca (7.1%) and Mg (20.8%), available Zn (10.9%), labile carbon (17.7%) and bulk density (12.2%) (Fig 37).

Table 38: Soil quality indices and relative soil quality indices of the long-term manurial treatments under pearl millet system in Aridisols of SK Nagar, Dantiwada

Treatments	SQI	RSQI
T1: Control	1.77	0.71
T2: 100 % RDN through urea	2.23	0.90
T3: 50 % RDN through urea	2.00	0.80
T4: 50 % RDN through FYM	2.37	0.95
T5: 50 % RDN (urea) + 50% RDN (FYM)	2.46	0.99
T6: Farmers method 5 t FYM ha^{-1} once in three years	2.31	0.93
CD @ 0.05	0.08	0.03

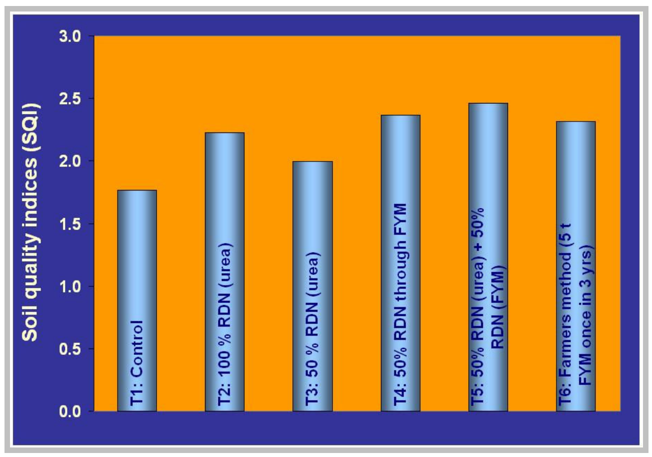


Fig 36: Soil quality indices as influenced by different long-term manurial treatments applied to pearl millet at Aridisols of SK Nagar, Dantiwada

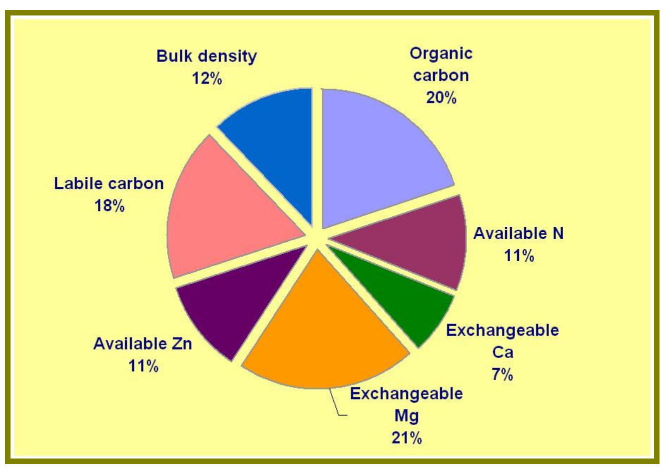


Fig 37: Percent contributions of key indicators towards soil quality indices as influenced by different long-term manurial treatments applied to pearl millet at Aridisols of SK Nagar, Dantiwada

Table 39: Summary of soil quality indices and relative soil quality indices as influenced by different long-term manurial treatments practiced in Aridisols of Sardar Krishi Nagar, Dantiwada

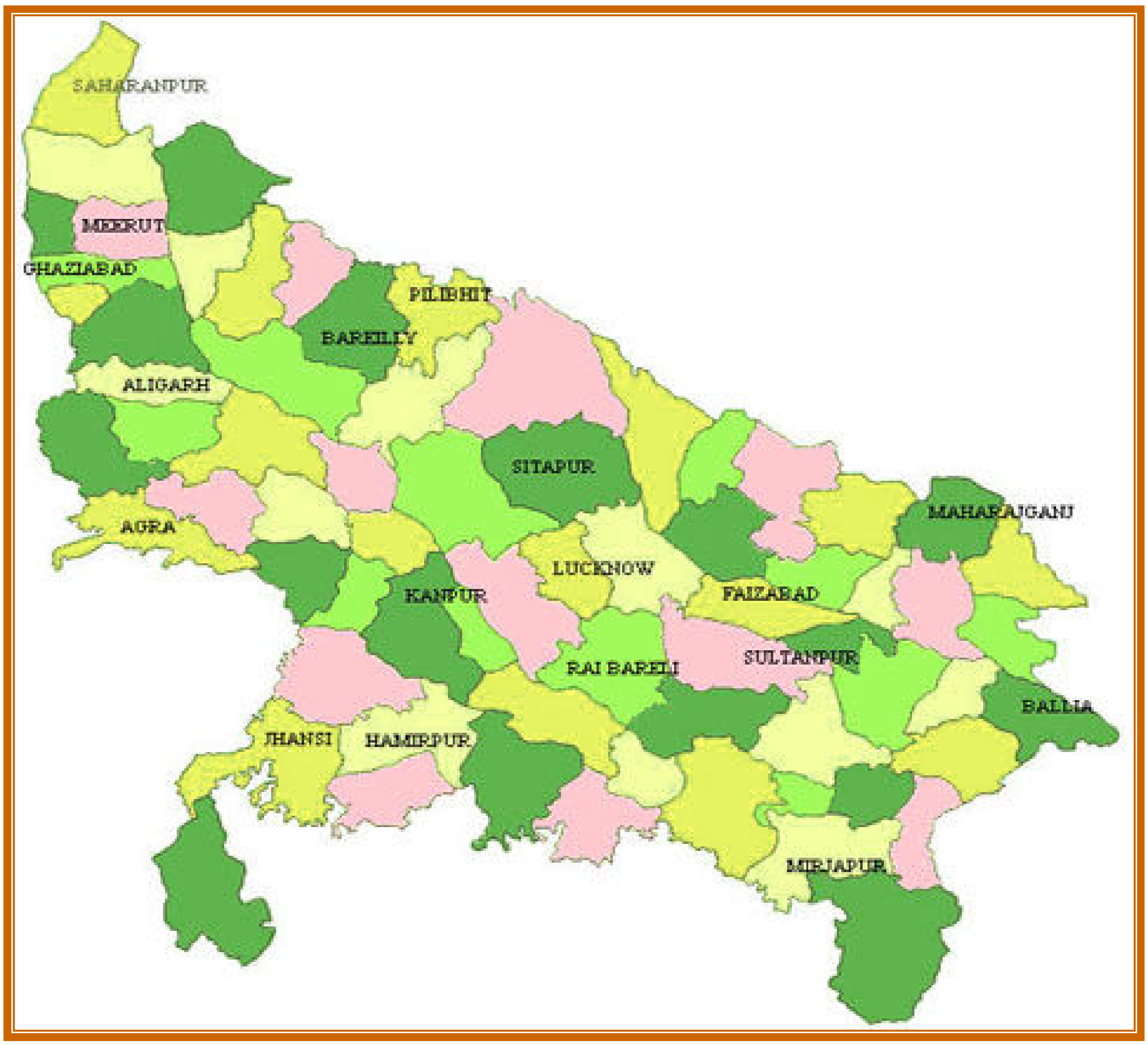
Sno		SQI	RSQI
Experiment 1: Long-term manurial trial			
1	T1: Control	1.77	0.71
2	T2: 100 % RDN through urea	2.23	0.90
3	T3: 50 % RDN through urea	2.00	0.80
4	T4: 50 % RDN through FYM	2.37	0.95
5	T5: 50 % RDN (urea) + 50% RDN (FYM)	2.46	0.99
6	T6: Farmers method 5 t FYM ha^{-1} once in three years	2.31	0.93

Table 40: Summary of key soil quality indicators, soil quality indices and the best soil nutrient management practices identified under long-term manurial treatments practiced in Aridisols of Sardar Krishi Nagar, Dantiwada

Sno	Key soil quality indicators and their % contribution	SQI	RSQI	Best management practices with higher SQI
Experiment 1: Long-term manurial trial				
	• Organic carbon (19.9%) • Available N (11.3%) • Exchangeable Ca (7.1%) • Exchangeable Mg (20.8%) • Available Zn (10.9%) • Labile carbon (17.7%) • Bulk density (12.2%)	1.77 – 2.46	0.71 – 0.99	1. Application of 50 % RDN (urea) + 50% RDN (FYM) (2.46) 2. Application of 50 % RDN through FYM (2.37) 3. Application of Farmers method 5 t FYM ha^{-1} once in three years (2.31)

Agra Centre

Pearl millet based production system



4.2.11.Effect of predominant soil and nutrient management practices on soil quality indicators (attributes) and soil quality indices at Agra centre of AICRPDA

Location description, climate and soil characteristics

Agra is in northern plain (and Central highlands) including Aravallis, North Punjab plain, Ganga Yamuna Doab, and Rajasthan upland (AESR 4.1). The climate is hot semi-arid. Annual potential evapo-transpiration is 669 mm. Annual rainfall is 669 mm. Length of growing period is 90-120 days. Drought occurs twice in five years. Water erosion is with extreme terrain deformation affecting 26-50% area; and moderate loss of topsoil, affecting 11-25% area. Very high severity to moderate is physical deterioration due to water logging, affecting 11-25% area of medium severity. The soils are deep loamy alluvium –derived soils (occasional saline and sodic phases). Available water capacity is medium. Soil reaction is neutral. Soil reaction is neutral. Electrical conductivity is suitable. Organic carbon is low. Phosphate and potash are medium. Agra centre has the recommendation domain of Agra, Aligarh, Hathras, Etah, Manipuri, Firozabad, and Mathura districts in Uttar Pradesh.

In order to study the effect of predominant soil and nutrient management practices on soil quality indicators, and the soil quality indices, the following experiments were chosen at Agra centre.

- Experiment 1: long-term experiment in major production system
- Experiment 2: Tillage and nutrient management for resource conservation and improving soil quality
- Experiment 3: Farmers fields

4.2.12. Experiment 1: Long-term experiment in major production system

This long-term experiment was initiated at Agra centre during the year 2002. This experiment was chosen for the soil quality assessment study, to identify the key indicators and also to choose the best nutrient management practices, which maintain the soil quality. The experiment was laid out in a randomized block design using eight nutrient management treatments in four replications using pearl millet as the test crop. Out of these eight treatments, only five treatments viz., have been chosen for the soil quality assessment study viz.,

T1: Control

T2: 50% urea + 50% Crop residue

T3: 50% urea + 50% FYM

T4: 100% RDF + 25 kg $ZnSO_4$,

T5: Farmers method

In this experiment, the soil quality assessment was taken up after four years of experimentation. The data on the influence of the long term integrated nutrient management treatments on various physical, chemical and biological soil quality parameters is presented in Tables 41 to 43.

The data revealed that except pH and EC, all the soil quality parameters were significantly influenced by the management treatments. Soil pH was neutral to slightly alkaline varying from 7.00 to 7.54 and the electrical conductivity varied from 0.23 to 0.30 across the management treatments. Organic carbon content was found to be highest under application of 50% urea + 50% FYM (4.23 g kg^{-1}) which was also at par with application of 100% RDF + 25 kg $ZnSO_4$ (3.84 g kg^{-1}) and 50% urea + 50% Crop residue (3.50 g kg^{-1}). Available nitrogen was observed to be low in these soils with highest under application of 50% urea + 50% FYM (150.9 kg ha^{-1}) and was at par with other treatments. Available P as well as available K was observed to be in the medium range varying from 10.6 to 26.6 kg ha^{-1} and 177.4 to 274.2 kg ha^{-1} across the management treatments. Application of 50% urea + 50% FYM recorded significantly highest available P (26.6 kg ha^{-1}) as well as available K (274.2 kg ha^{-1}).

Table 41: Influence of long-term manurial treatments on physico-chemical and chemical soil quality parameters under pearl millet system in Entisols of Agra

SNo	Name of the treatments	pH	EC dS m^{-1}	OC (g kg^{-1})	N	P	K
					(kg ha^{-1})		
1	T1: Control	7.00	0.25	2.91	122.8	10.6	177.4
2	T2: 50% urea + 50% Crop residue	7.54	0.30	3.50	140.6	16.2	274.1
3	T3: 50% urea + 50% FYM	7.03	0.26	4.23	150.9	26.6	274.2
4	T4: 100% RDF + 25 kg $ZnSO_4$	7.36	0.23	3.84	140.4	16.4	241.5
5	T5: Farmers method	7.26	0.24	3.44	135.7	14.2	207.7
	CD @ 0.05	NS	NS	0.76	14.7	4.11	46.6

Exchangeable Ca and Mg varied from 3.99 to 5.14 cmol kg^{-1} and 1.53 to 2.45 c-mol kg^{-1} respectively across the management treatments. Application of 100% RDF + 25 kg $ZnSO_4$ recorded significantly highest available S (32.2 kg ha^{-1}) which was at par with 50% urea + 50% FYM (29.1 kg ha^{-1}) while the lowest was observed in control plot (20.8 kg ha^{-1}). Among the micronutrients, available Zn, Fe, Cu and Mn were high in these soils while available B was in medium range. Application of 50% urea + 50% FYM recorded significantly highest available Fe (14.3 μg g^{-1}), available Cu (2.40 μg g^{-1}) and available B (0.52 μg g^{-1}) and was at par with other INM treatments also.

Table 42: Influence of long-term manurial treatments on chemical soil quality parameters (Secondary and micronutrients) under pearl millet system in Entisols of Agra

SNo	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		cmol kg^{-1}		(kg ha^{-1})	μg g^{-1}				
1	T1: Control	3.99	1.53	20.8	1.34	8.14	1.18	9.51	0.36
2	T2: 50% urea + 50% Crop residue	5.14	1.57	27.0	1.42	12.2	1.78	13.2	0.52
3	T3: 50% urea + 50% FYM	4.67	2.44	29.1	1.79	14.3	2.40	14.6	0.52
4	T4: 100% RDF + 25 kg $ZnSO_4$	5.02	2.45	32.2	3.32	13.0	2.25	14.2	0.46
5	T5: Farmers method	4.06	2.45	24.5	2.29	12.7	1.48	16.8	0.38
	CD @ 0.05	0.82	0.37	5.05	0.65	3.66	0.62	2.82	0.12

The long-term practice of integrated nutrient management practices had a significant influence on biological as well as physical soil quality parameters. Dehydrogenase activity varied from 4.54 to 7.69 μg TPF $hr^{-1}g^{-1}$, microbial biomass carbon from 34.2 to 53.4 μg g^{-1} of soil and labile carbon from 227.6 to 323.1 μg g^{-1} of soil across the management treatments. The physical soil quality parameters viz., bulk density varied from 1.19 to 1.33 Mg m^{-3} while the mean weight diameter varied from 0.21 to 0.35 across the management treatments. Among the treatments, it was observed that application of 50% urea + 50% Crop residue as well as 50% urea + 50% FYM maintained highest soil biological as well as physical soil quality.

Table 43: Influence of long-term manurial treatments on biological and physical soil quality parameters (secondary and micronutrients) under pearl millet system in Entisols of Agra

SNo	Name of the treatments	DHA (µg TPF $hr^{-1}g^{-1}$)	MBC (µg g^{-1} of soil)	LC (µg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	T1: Control	4.54	34.2	227.6	1.33	0.21
2	T2: 50% urea + 50% Crop residue	7.69	51.5	306.1	1.19	0.30
3	T3: 50% urea + 50% FYM	7.61	53.4	323.1	1.21	0.35
4	T4: 100% RDF + 25 kg $ZnSO_4$	7.17	41.4	285.7	1.28	0.27
5	T5: Farmers method	7.01	42.9	280.6	1.32	0.24
	CD @ 0.05	1.27	7.27	28.3	0.07	0.07

4.2.12.1. Key indicators and soil quality assessment

4.2.12.2. Results of principal component analysis

The long-term influence of integrated nutrient management treatments practiced under pearl millet system on 19 soil quality indices has been studied and it was observed that out of 19 soil quality parameters, two variables viz., pH and EC were not significantly influenced by the management treatments and were dropped from the PCA. In the PCA of 17 variables, three PCs had eigen values >1 and explained 79.0% variance in the data set (Table 44). In PC1, five variables were qualified as the highly weighted variables viz., organic carbon, available N, available Cu, labile carbon and mean weight diameter (MWD). In PC2, exchangeable Mg and available Zn were the highly weighted variables while in PC3, only exchangeable Ca was the highly weighted variable. The correlation matrix (Table 45) run for the variables qualified under PC1 revealed quite significant correlation between all the five parameters. Among these five variables, labile carbon had the highest correlation sum (3.93) followed by mean weight diameter (3.89) apart from the good correlation between them. But, considering their importance, both were retained for the final MDS. Apart from these two, the other parameters, ie., OC, available N and Cu were also retained for the final MDS. In PC2, the correlation analysis between the variables qualified revealed a significant correlation and hence available Zn was retained for final MDS while exchangeable Mg was dropped from the final MDS. Hence the final parameters which were retained for the final MDS were: organic carbon, available N, exchangeable Ca, Available Zn and Cu, labile carbon and mean weight diameter and were termed as the key indicators for pearl millet system under Entisols of Agra.

Table 44: Principal component analysis of soil quality parameters as influenced by different INM treatments under pearl millet system in Entisols of Agra

Sno	PC1	PC2	PC3
Total Eigen values	9.393	2.665	1.368
% of Variance	55.253	15.678	8.047
Cumulative %	55.253	70.930	78.977
Eigen Vectors			
OC	**0.825**	0.074	0.247
N	**0.850**	0.131	-0.256
P	0.816	-0.129	-0.127
K	0.813	-0.180	0.055
Ca	0.651	-0.287	**0.543**
Mg	0.513	**0.795**	-0.031
S	0.736	0.200	0.465
Zn	0.297	**0.816**	0.293
Fe	0.778	0.323	-0.197
Cu	**0.821**	0.230	0.104
Mn	0.559	0.525	-0.432
B	0.716	-0.440	0.356
DHA	0.812	0.041	-0.022
MBC	0.767	-0.323	-0.445
LC	**0.912**	-0.160	-0.173
BD	-0.650	0.603	0.178
MWD	**0.861**	-0.228	-0.009

Table 45: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs					
PC1	**OC**	**N**	**Cu**	**LC**	**MWD**
OC	1.00	0.574*	0.685**	0.779**	0.703**
N	0.574*	1.00	0.787**	0.733**	0.759**
Cu	0.685**	0.787**	1.00	0.669**	0.679**
LC	0.779**	0.733**	0.669**	1.00	0.750**
MWD	0.703**	0.759**	0.679**	0.750**	1.00
Correlation sum	**3.741**	**3.853**	**3.820**	**3.931**	**3.891**
PC2	**Mg**	**Zn**			
Mg	1.00	0.735**			
Zn	0.735**	1.00			
Correlation sum	1.735	1.735			

*correlation is significant at P = 0.05 level
**correlation is significant at P = 0.01 level

4.2.12.3. Soil quality indices

Soil quality indices were computed using seven key soil quality indicators viz.., organic carbon, available N, exchangeable Ca, Available Zn and Cu, labile carbon and mean weight diameter. The soil quality indices varied from 2.33 to 3.47 across the long-term integrated nutrient management treatments practiced for pearl millet system (Table 46 & Fig 38). For simple understanding, the soil quality indices were reduced to a scale of one, termed as 'relative soil quality indices' (RSQI), which varied between 0.64 to 0.95. Among all the manurial treatments practiced, the application of 50% urea + 50% FYM showed the highest soil quality index of 3.47 which was at par with 100% RDF + 25 kg $ZnSO_4$ (3.20). Irrespective of their statistical significance, the relative order of performance of the INM treatments in influencing soil quality in terms of SQI was: T3: 50% urea + 50% FYM (3.47) > T4: 100% RDF + 25 kg $ZnSO_4$ (3.20) > T2: 50% urea + 50% Crop residue (3.01) > T5: Farmers method (2.77) > T1: Control (2.33). The average percent contribution of key indicators towards soil quality indices was: organic carbon (19%), available N (20%), exchangeable Ca (3%), Available Zn (4%) and Cu (17%), labile carbon (20%) and mean weight diameter (17%) (Fig 39).

Table 46: Soil quality indices and relative soil quality indices of the long-term integrated nutrient management treatments under pearl millet system in Entisols of Agra

	Treatments	SQI	RSQI
1	T1: Control	2.33	0.64
2	T2: 50% urea + 50% Crop residue	3.01	0.83
3	T3: 50% urea + 50% FYM	3.47	0.95
4	T4: 100% RDF + 25 kg $ZnSO_4$	3.20	0.88
5	T5: Farmers method	2.77	0.76
	CD @ 0.05	0.35	0.10

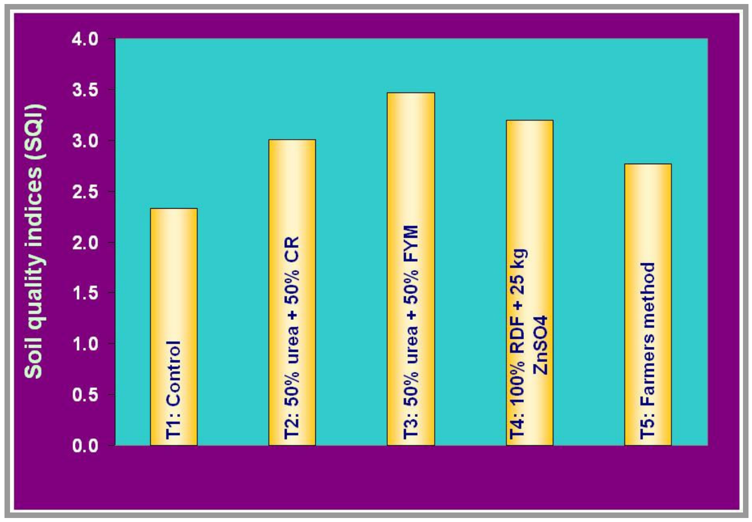


Fig 38: Soil quality indices of the long-term integrated nutrient management treatments under pearl millet system in Entisols of Agra

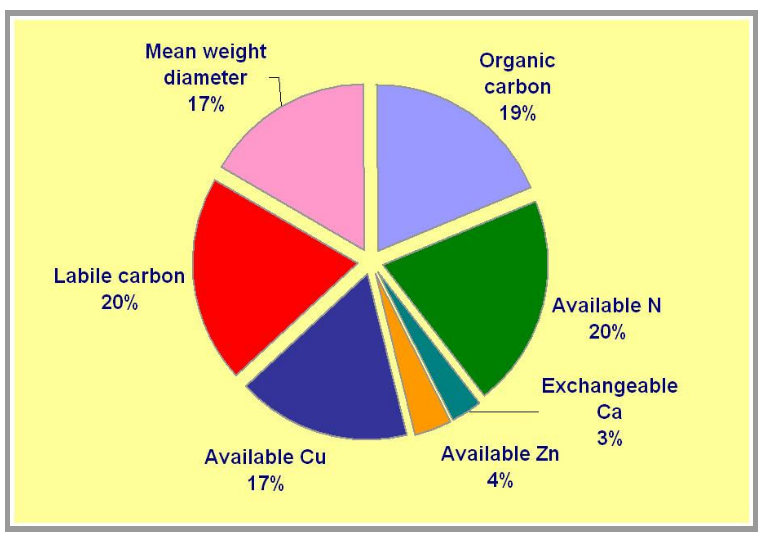


Fig 39: Percent contributions of key soil quality indicators towards soil quality indices of the long-term integrated nutrient management treatments under pearl millet system in Entisols of Agra

4.2.13. Experiment 2: Tillage and nutrient management for resource conservation and improving soil quality

This experiment was initiated during the year 2000 at Agra centre with an objective to study the influence of tillage and nutrient management practices on resource conservation and improving soil quality. The experiment was chosen for this soil quality assessment studies to identify the key indicators and also to identify the best soil and nutrient management practices, which could help in maintaining the soil quality. The experiment was laid out in a split plot design with three main treatments and three sub treatments in three replications using pearl millet as test crop. The main treatments comprised of three tillage treatments viz., T1: Conventional tillage, T2: Low tillage + one interculture and T3: 3.Low tillage + weedicide + one interculture while the sub treatments included three nutrient management treatments viz., T1: 100% N (organic), T2: 2.50% N (organic) + 50% N (inorganic) and T3: 3.100% N (inorganic). Hence the nine treatments in all were:

T1: CT + IC + 100% N (organic source/compost)
T2: CT + IC + 50% N (organic) + 50 % inorganic source)
T3: CT + IC + 100% N (inorganic source)
T4: LT + IC + 100% N (organic source/compost)
T5: LT + IC + 50% N (organic) + 50 % inorganic source)
T6: LT + IC + 100% N (inorganic source)
T7: LT + Weedicide + IC + 100% N (organic source/compost)
T8: LT + Weedicide + IC + 50% N (organic) + 50 % inorganic source)
T9: LT + Weedicide + IC + 100% N (inorganic source)

The soil quality assessment studies in this experiment were undertaken after five years of experimentation and the results on the influence of tillage and nutrient management practices on various physical, chemical and biological soil quality parameters have been presented in Tables 47 to 49.

Tillage and the nutrient management practices showed no influence on soil pH as well as electrical conductivity of these soils. However, the soil pH varied from 7.18 to 7.85 while the electrical conductivity varied from 0.26 to 0.37 dSm^{-1} across the management treatments. Organic carbon, which varied from 3.59 to 4.84 g kg^{-1} across the treatments, was significantly influenced by both tillage as well as nutrient management treatments while their interaction effects were not significant. Among the tillage, practice of conventional tillage along with one interculture recorded significantly highest organic carbon content (4.67 g kg^{-1}) followed by the practice of low tillage + one interculture (4.21 g kg^{-1}) while the practice of low tillage + one interculture + weedicide application recorded the lowest organic carbon content of 3.89 g kg^{-1}. Among the nutrient management practices, application of nutrients through 100% organics recorded significantly highest organic carbon content (4.59 g kg^{-1}) followed by application of 50% N (organics) + 50% N (inorganics) (4.10 g kg^{-1}) which was at par with application of nutrients through 100% inorganics (4.10 g kg^{-1}). Among the macronutrients, available nitrogen, which ranged from 115.7 to 136.0 kg ha^{-1} across the management practices, was significantly influenced by the nutrient management treatments alone but not by any tillage effects. Among the nutrient management treatments, application of nutrients through 100% organics recorded significantly highest available nitrogen of 133.3 kg ha^{-1}, which was also at par with application of 100% inorganics (127.1 kg ha^{-1}). Available P was high ranging from 27.1 to 42.7 kg ha^{-1} across the management treatments and was neither influenced by tillage nor nutrient management practices. Available K was observed to be medium to high in these soils varying from 189.7 to 329.0 kg ha^{-1} across the management practices and was significantly influenced only by various tillage practices of which practice of conventional tillage + one interculture maintained higher available K (308.5 kg ha^{-1}).

Table 47: Effect of tillage and nutrient management practices on physico chemical and chemical soil quality parameters (macronutrients) under pearl millet system in Entisols of Agra

SNo	Name of the treatments	pH	EC dS m^{-1}	OC (g kg^{-1})	N	P	K
					(kg ha^{-1})		
1	CT + IC + 100% N (organic source/compost)	7.39	0.31	4.84	131.1	30.8	269.1
2	CT + IC + 50% N (organic) + 50 % inorganic source)	7.76	0.37	4.74	118.6	33.8	329.0
3	CT + IC + 100% N (inorganic source)	7.85	0.32	4.44	127.5	37.9	327.4
4	LT + IC + 100% N (organic source/compost)	7.43	0.29	4.70	132.8	34.8	267.1
5	LT + IC + 50% N (organic) + 50 % inorganic source)	7.39	0.27	3.72	115.7	31.7	189.7
6	LT + IC + 100% N (inorganic source)	7.18	0.28	4.20	124.6	27.1	246.1
7	LT + Weedicide + IC + 100% N (organic source/compost)	7.60	0.27	4.23	136.0	29.7	216.6
8	LT + Weedicide + IC + 50% N (organic) + 50 % inorganic source)	7.73	0.29	3.83	124.6	33.2	270.9
9	LT + Weedicide + IC + 100% N (inorganic source)	7.64	0.26	3.59	129.1	42.7	278.2
	CD @ 0.05						
	Between two main treatment means	NS	NS	0.37	NS	NS	25.0
	Between two sub treatment means	NS	NS	0.34	9.14	NS	NS

SNo	Name of the treatments	pH	EC dS m^{-1}	OC (g kg^{-1})	N	P	K
					(kg ha^{-1})		
	Between two sub treatment means at same main treatments	NS	NS	NS	NS	7.85	NS
	Between two main treatment means at same or different sub treatments	NS	NS	NS	NS	7.89	NS

Among the secondary nutrient parameters, exchangeable Ca varied from 3.38 to 5.02 cmol kg^{-1}, exchangeable Mg from 2.48 to 3.35 cmol kg^{-1} and available S from 24.6 to 39.5 kg ha^{-1} across the treatments. It was observed that tillage showed significant influence only on exchangeable Ca but not on exchangeable Mg and available S. On the other hand, the nutrient management practices did not show any significant influence on exchangeable Ca and Mg but significantly influenced available S where, application of nutrients through 100% organic sources recorded significantly highest available S (38.7 kg ha^{-1}). The interaction effects of tillage as well as the nutrient management treatments was observed on exchangeable Mg and available S but not on exchangeable Ca. Among the micronutrients, it was observed that the practice of tillage did not show any significant influence on any of the micronutrients while the practice of the nutrient management practices showed a significant influence on all the micronutrients except available B. The interaction effect of both tillage and nutrient management practices was observed only on available Cu and B. Among the nutrient management practices followed, application of nutrients through 50% N (organic) + 50 % inorganic sources recorded significantly highest available Zn (1.91 μg g^{-1}), Fe (15.9 μg g^{-1}), Cu (0.87 μg g^{-1}) and Mn (15.6 μg g^{-1}).

Table 48: Effect of tillage and nutrient management practices on chemical soil quality parameters (secondary and micronutrients) under pearl millet system in Entisols of Agra

SNo	Name of the treatments	Ca	Mg	S (kg ha^{-1})	Zn	Fe	Cu	Mn	B
		cmol kg^{-1}			μg g^{-1}				
1	CT + IC + 100% N (organic source/compost)	5.02	3.04	39.5	1.55	16.5	0.91	10.5	0.58
2	CT + IC + 50% N (organic) + 50 % inorganic source)	3.89	2.48	24.7	1.77	18.2	0.69	16.9	0.66
3	CT + IC + 100% N (inorganic source)	4.09	3.04	35.5	1.31	14.7	0.63	11.8	0.51
4	LT + IC + 100% N (organic source/compost)	3.56	3.35	38.7	1.56	13.3	0.63	12.5	0.62
5	LT + IC + 50% N (organic) + 50 % inorganic source)	3.38	3.10	24.6	1.99	15.1	0.61	13.5	0.53

SNo	Name of the treatments	Ca	Mg	S (kg ha^{-1})	Zn	Fe	Cu	Mn	B
		cmol kg^{-1}			µg g^{-1}				
6	LT + IC + 100% N (inorganic source)	4.11	2.78	34.5	1.47	12.2	0.88	10.8	0.53
7	LT + Weedicide + IC + 100% N (organic source/compost)	4.95	2.72	37.8	1.83	13.5	0.46	10.0	0.56
8	LT + Weedicide + IC + 50% N (organic) + 50 % inorganic source)	4.43	3.23	28.5	1.98	14.3	1.31	16.3	0.38
9	LT + Weedicide + IC + 100% N (inorganic source)	4.25	3.08	24.8	1.32	14.7	0.94	13.4	0.59
	CD @ 0.05								
	Between two main treatment means	0.38	NS	NS	NS	NS	NS	NS	NS
	Between two sub treatment means	NS	NS	3.33	0.38	1.62	0.16	2.95	NS
	Between two sub treatment means at same main treatments	NS	0.54	5.76	NS	NS	0.27	NS	0.11
	Between two main treatment means at same or different sub treatments	NS	0.50	7.13	NS	NS	0.26	NS	0.13

Among the biological soil quality parameters, the adoption of different tillage practices showed a significant influence only on dehydrogenase activity but not on microbial biomass carbon and labile carbon, while the nutrient management practices showed a significant influence on all the three biological soil quality parameters. Among the tillage practices, practice of low tillage + one interculture + weedicide recorded higher dehydrogenase activity of 7.44 µg TPF hr^{-1}g^{-1}. Among the nutrient management practices, application of nutrients through 100% organic sources recorded significantly highest dehydrogenase activity (7.78 µg TPF hr^{-1}g^{-1}), microbial biomass carbon (60.1 µg g^{-1} of soil) as well as labile carbon (275.7 µg g^{-1} of soil). Secondly, the influence of tillage was significant on bulk density but not on mean weight diameter while the influence of the nutrient management practices was significant on both bulk density as well as mean weight diameter. Bulk density varying from 1.20 to 1.35 Mg m^{-3} across the management treatments was significantly lowest under practice of conventional tillage + one interculture (1.23 Mg m^{-3}). When the influence of nutrient management practices was concerned, it was observed that application of nutrients through 100% organic sources maintained significantly lowest bulk density (1.23 Mg m^{-3}) with a highest mean weight diameter of 0.31 mm.

Table 49: Effect of tillage and nutrient management practices on biological and physical soil quality parameters under pearl millet system in Entisols of Agra

SNo	Name of the treatments	DHA (µg TPF $hr^{-1}g^{-1}$)	MBC (µg g^{-1} of soil)	LC (µg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	CT + IC + 100% N (organic source/compost)	7.68	61.5	262.7	1.20	0.29
2	CT + IC + 50% N (organic) + 50 % inorganic source)	5.56	42.2	241.6	1.21	0.23
3	CT + IC + 100% N (inorganic source)	4.35	44.7	234.0	1.28	0.25
4	LT + IC + 100% N (organic source/compost)	7.31	60.2	282.8	1.26	0.30
5	LT + IC + 50% N (organic) + 50 % inorganic source)	6.91	48.2	259.1	1.28	0.24
6	LT + IC + 100% N (inorganic source)	5.19	50.4	237.9	1.25	0.23
7	LT + Weedicide + IC + 100% N (organic source/compost)	8.35	58.5	248.3	1.25	0.32
8	LT + Weedicide + IC + 50% N (organic) + 50 % inorganic source)	7.20	49.2	247.5	1.28	0.26
9	LT + Weedicide + IC + 100% N (inorganic source)	6.77	50.8	233.3	1.35	0.24
	CD @ 0.05					
	Between two main treatment means	0.89	NS	NS	0.04	NS
	Between two sub treatment means	0.63	6.33	15.9	0.04	0.03
	Between two sub treatment means at same main treatments	NS	NS	NS	NS	NS
	Between two main treatment means at same or different sub treatments	NS	NS	NS	NS	NS

4.2.13.1. Key indicators and soil quality assessment

4.2.13.2. Results of principal component analysis

The long-term influence of tillage and nutrient management treatments practiced under pearl millet system on 19 soil quality indices has been studied and it was observed that out of 19 soil quality parameters, only two variables viz., pH and EC were not significantly influenced neither by tillage nor the nutrient management treatments and were dropped from the PCA. In the PCA of 17 variables, six PCs had eigen values >1 and explained 74.3% variance in the data set (Table 50). In PC1, only two variable viz., microbial biomass carbon and mean weight diameter were qualified as the highly weighted variables. In the rest of the PCs, only single variables were found to be highly weighted viz., organic carbon in PC2, available Zn in PC3, exchangeable Ca in PC4, available Cu in PC5 and dehydrogenase assay in PC6 and were to be retained for the minimum data set (MDS). The correlation matrix (Table 51) run for the variables qualified under PC1 revealed a significant correlation (0.696**) but both the variables under PC1 were retained for the MDS considering the important role they play towards soil quality. Hence, the final parameters retained for the minimum data set were: organic carbon, exchangeable Ca, available Zn, available Cu, dehydrogenase assay, microbial biomass carbon and mean weight diameter and were termed as the key indicators for pearl millet system under Entisols of Agra.

Table 50: Principal component analysis of soil quality parameters as influenced by different tillage and nutrient management treatments under pearl millet system

Sno	PC1	PC2	PC3	PC4	PC5	PC6
Total Eigen values	4.083	2.574	2.020	1.558	1.315	1.082
% of Variance	24.019	15.141	11.887	9.166	7.734	6.363
Cumulative %	24.019	39.159	51.047	60.213	67.947	74.310
Eigen Vectors						
OC	0.310	**0.784**	-0.206	0.049	0.120	-0.177
N	0.624	-0.135	0.563	-0.007	0.042	0.052
P	-0.326	-0.059	0.550	0.370	0.136	0.325
K	-0.276	0.491	0.425	-0.044	0.425	-0.234
Ca	0.416	0.089	0.271	**-0.647**	0.189	0.409
Mg	0.251	-0.377	0.246	0.502	0.337	-0.389
S	0.741	0.296	0.071	-0.223	-0.060	-0.245
Zn	-0.040	-0.209	**-0.745**	-0.111	0.066	-0.018
Fe	-0.311	0.575	-0.125	0.273	0.358	0.324
Cu	-0.182	-0.391	0.066	-0.326	**0.605**	-0.102
Mn	-0.547	0.058	-0.311	0.030	0.483	0.200
B	0.135	0.635	0.155	0.355	-0.281	0.289
DHA	0.547	-0.420	-0.339	0.149	0.078	**0.470**
MBC	**0.873**	-0.149	0.041	0.075	0.132	0.018
BD	-0.391	-0.571	0.290	0.249	-0.161	0.090
MWD	**0.812**	-0.023	0.009	0.063	0.224	0.174
LC	0.554	0.000	-0.378	0.532	0.187	-0.100

Table 51: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs		
PC1	**MBC**	**MWD**
MBC	1.00	0.696**
MWD	0.696**	1.00
Correlation sum	1.696	1.696

**correlation is significant at P = 0.01 level

4.2.13.3. Soil quality indices

Soil quality indices were computed using seven key soil quality indicators viz.., organic carbon, exchangeable Ca, available Zn, available Cu, dehydrogenase assay, microbial biomass carbon and mean weight diameter. The soil quality indices varied from 0.86 to 1.08 across the tillage and nutrient management treatments practiced for pearl millet system (Table 52 & Fig 40, 41). For simple understanding, the soil quality indices were reduced to a scale of one, termed as 'relative soil quality indices' (RSQI), which varied between 0.72 to 0.90. It was observed that tillage as well as the nutrient management treatments played a significant role in influencing the soil quality indices while their interaction effects were not so conspicuous on soil quality indices. Among the tillage treatments, practice of low tillage with one interculture + weedicide application resulted in higher soil quality index of 0.98 followed by practice of conventional tillage + one interculture (0.94) which was at par with the practice of low tillage + one interculture (0.93). Among the nutrient management treatments, application of nutrients through 100% organic sources maintained highest soil quality with SQI value of 1.05 while the other two nutrient management practices viz., 50% N (organic) + 50 % (inorganic source) as well as 100% N (inorganic source) with SQI values of 0.92 and 0.88 respectively, maintained soil quality at par with each other. Irrespective of their statistical significance, the relative order of performance in influencing soil quality in terms of SQI was: CT + IC + 100% N (organic source/compost) (1.08) > LT + Weedicide + IC + 100% N (organic source/compost) (1.05) > LT + IC + 100% N (organic source/compost) (1.02) > LT + Weedicide + IC + 50% N (organic) + 50 % inorganic source) (0.99) > LT + Weedicide + IC + 100% N (inorganic source) (0.90) > LT + IC + 100% N (inorganic source) (0.89) > CT + IC + 50% N (organic) + 50 % inorganic source) (0.88) = LT + IC + 50% N (organic) + 50 % inorganic source) (0.88) > CT + IC + 100% N (inorganic source) (0.86). The average percent contribution of key indicators towards soil quality indices was: organic carbon (17%), exchangeable Ca (10%), available Zn (9%), available Cu (6%), dehydrogenase assay (6%), microbial biomass carbon (25%) and mean weight diameter (27%) (Fig 42).

Table 52: Soil quality indices and relative soil quality indices of the long-term tillage and nutrient management treatments under pearl millet system in Entisols of Agra

	Treatments	SQI	RSQI
1	CT + IC + 100% N (organic source/compost)	1.08	0.90
2	CT + IC + 50% N (organic) + 50 % inorganic source)	0.88	0.74
3	CT + IC + 100% N (inorganic source)	0.86	0.72
4	LT + IC + 100% N (organic source/compost)	1.02	0.85

	Treatments	SQI	RSQI
5	LT + IC + 50% N (organic) + 50 % inorganic source)	0.88	0.74
6	LT + IC + 100% N (inorganic source)	0.89	0.74
7	LT + Weedicide + IC + 100% N (organic source/compost)	1.05	0.88
8	LT + Weedicide + IC + 50% N (organic) + 50 % inorganic source)	0.99	0.83
9	LT + Weedicide + IC + 100% N (inorganic source)	0.90	0.75
	CD @ 0.05		
	Between two main treatment means	0.04	NS
	Between two sub treatment means	0.06	0.05
	Between two sub treatment means at same main treatments	NS	NS
	Between two main treatment means at same or different sub treatments	NS	NS

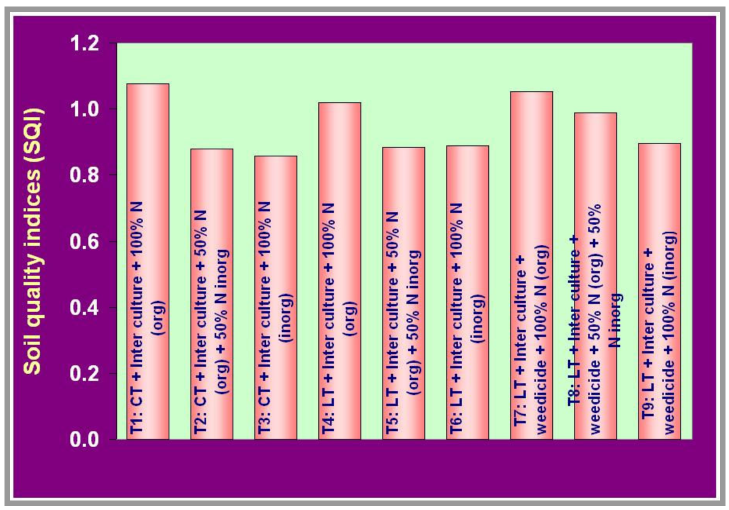


Fig 40: Soil quality indices as influenced by tillage and nutrient management treatments under pearl millet system in Entisols of Agra

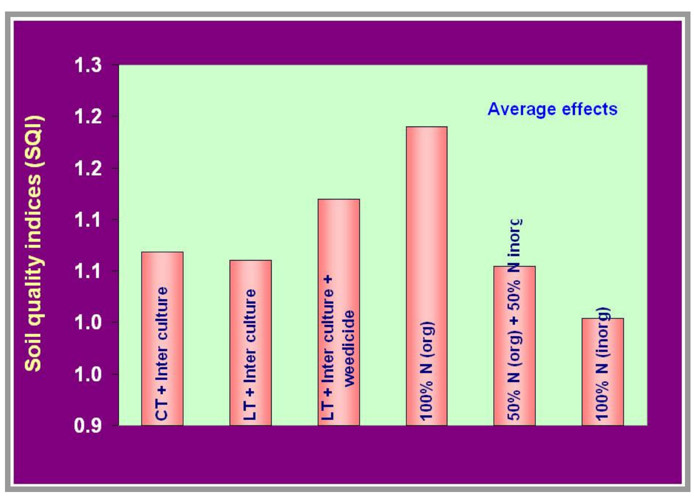


Fig 41: Average effects of tillage and nutrient management treatments on soil quality indices under - pearl millet system in Entisols of Agra

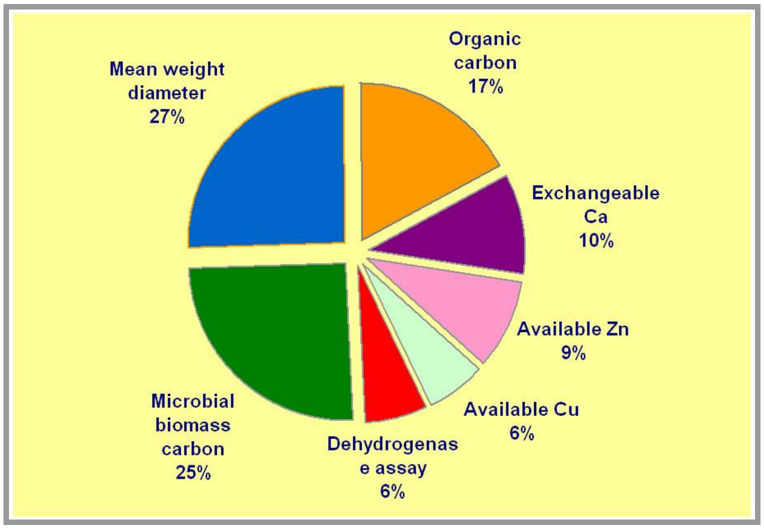


Fig 42: Percent contributions of key soil quality indicators towards soil quality indices as influenced by tillage and nutrient management treatments under pearl millet system in Entisols of Agra

4.2.14. Experiment 3: Farmers fields

Three cropping systems selected under farmer's fields at Agra were evaluated for their performance in maintaining soil quality for which all the physical, chemical and biological soil quality parameters were analyzed and the data is presented in Tables 53 to 55. On the whole, it was observed that, except for available P, K, labile carbon and bulk density, the influence of cropping systems was not conspicuous on any of the soil quality parameters chosen under this study. The soils were neutral to slightly alkaline in reaction with pH varying from 7.05 to 7.68 and electrical conductivity ranging from 0.25 to 0.32 dSm^{-1}. Organic carbon as well as available N under these cropping systems was low ranging from 4.20 to 4.56 g kg^{-1} and 130.6 to 141.8 kg ha^{-1} respectively. On the other hand, available P was medium to high varying from 22.6 to 43.7 kg ha^{-1} while available K was medium varying from 183.2 to 271.1 kg ha^{-1} across the cropping systems. Available S as well as the micronutrient contents was also high in these soils.

Table 53: Influence of different cropping systems on physico chemical and chemical soil quality parameters (macronutrients) under farmer's fields in Entisols of Agra

SNo	Name of the treatments	pH	EC dS m^{-1}	OC (g kg^{-1})	N	P	K
					(kg ha^{-1})		
1	Pigeon pea + Green gram	7.05	0.32	4.43	141.8	22.6	183.2
2	Green gram + Mustard	7.06	0.25	4.20	138.1	43.7	198.3
3	Pearl millet + Cluster bean	7.68	0.31	4.56	130.6	31.3	271.1
	CD @ 0.05	NS	NS	NS	NS	7.42	54.8

Table 54: Influence of different cropping systems on physico chemical and chemical soil quality parameters (secondary and micronutrients) under farmer's fields in Entisols of Agra

SNo	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		cmol kg^{-1}		(kg ha^{-1})	μg g^{-1}				
1	Pigeon pea + Green gram	4.52	2.58	25.2	1.53	8.94	1.03	11.4	0.54
2	Green gram + Mustard	5.68	2.10	23.0	1.57	12.4	1.28	8.65	0.50
3	Pearl millet + Cluster bean	4.26	2.59	22.9	1.85	11.1	0.75	10.5	0.54
	CD @ 0.05	NS	NS	NS	NS	NS	NS	NS	NS

Among the biological soil quality parameters, dehydrogenase activity was quite good ranging from 7.21 to 9.04 μg TPF $hr^{-1}g^{-1}$ across the cropping systems, while the microbial biomass carbon values were recorded to be low as the analysis was carried out in dry soil samples. On the other hand, labile carbon was high and significantly highest under pigeonpea + green gram system (263.1 μg g^{-1} of soil) followed by green gram and mustard system (235.6 μg g^{-1} of soil) while the lowest was recorded under pearl millet + cluster bean system (226.8 μg g^{-1} of soil). Contrarily, bulk density was lowest under pearl millet + cluster bean system (1.29 Mg m^{-3}) and was highest under green gram + mustard system (1.39 Mg m^{-3}).

Table 55: Influence of different cropping systems on biological and physical soil quality parameters (secondary and micronutrients) under farmer's fields in Entisols of Agra

SNo	Name of the treatments	DHA (μg TPF $hr^{-1}g^{-1}$)	MBC (μg g^{-1} of soil)	LC (μg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	Pigeon pea + Green gram	9.04	55.9	263.1	1.37	0.20
2	Green gram + Mustard	7.21	59.4	235.6	1.39	0.21
3	Pearl millet + Cluster bean	8.00	56.9	226.8	1.29	0.23
	CD @ 0.05	NS	NS	24.0	0.05	NS

4.2.14.1. Computation of soil quality indices

In this experiment, most of the soil quality parameters were found to be non-significant between various cropping systems except available P, K, labile carbon and bulk density. Hence, soil quality indices could not be computed for these farmers' fields.

Table 56: Summary of soil quality indices and relative soil quality indices as influenced by different soil nutrient management practices under different trials practiced in Entisols of Agra.

Sno		SQI	RSQI
Experiment 1: Long-term integrated nutrient management treatments under pearl millet system			
1	T1: Control	2.33	0.64
2	T2: 50% urea + 50% Crop residue	3.01	0.83
3	T3: 50% urea + 50% FYM	3.47	0.95
4	T4: 100% RDF + 25 kg $ZnSO_4$	3.20	0.88
5	T5: Farmers method	2.77	0.76
Experiment 2: Tillage and nutrient management for resource conservation and improving soil quality			
1	CT + IC + 100% N (organic source/compost)	1.08	0.90
2	CT + IC + 50% N (organic) + 50 % inorganic source)	0.88	0.74
3	CT + IC + 100% N (inorganic source)	0.86	0.72
4	LT + IC + 100% N (organic source/compost)	1.02	0.85
5	LT + IC + 50% N (organic) + 50 % inorganic source)	0.88	0.74
6	LT + IC + 100% N (inorganic source)	0.89	0.74
7	LT + Weedicide + IC + 100% N (organic source/compost)	1.05	0.88
8	LT + Weedicide + IC + 50% N (organic) + 50 % inorganic source)	0.99	0.83
9	LT + Weedicide + IC + 100% N (inorganic source)	0.90	0.75
Experiment 3: Farmers fields			
1	Pigeon pea + Green gram	-	-
2	Green gram + Mustard	-	-
3	Pearl millet + Cluster bean	-	-
	CD @ 0.05		

Table 57: Summary of key soil quality indicators, soil quality indices and the best soil nutrient management practices identified under different cropping systems in Entisols of Agra.

Sno	Key soil quality indicators and their % contribution	SQI	RSQI	Best management practices with higher SQI
Experiment 1: Long-term integrated nutrient management treatments under pearl millet system				
	• Mean weight diameter (29%) • Labile carbon (28%) • Dehydrogenase assay (26%) • Organic carbon (10%) • Available S (7%)	2.33 – 3.47	0.64 – 0.95	1. Application of FYM@ 5 t ha^{-1} (2.47) 2. Application of 25% RDF + FYM@ 2.5 t ha^{-1} (2.43) 3. Application of 25% RDF + Gliricidia @ 1.5 t ha^{-1} (2.31)
Experiment 2: Tillage and nutrient management for resource conservation and improving soil quality				
	• Organic carbon (17%) • Exchangeable Ca (10%) • Available Zn (9%) • Available Cu (6%) • Dehydrogenase assay (6%) • Microbial biomass carbon (25%) • Mean weight diameter (27%)	0.56 – 1.08	0.72 - 0.90	1. CT + IC + 100% N (organic source/compost) (1.08) 2. LT + Weedicide + IC + 100% N (organic source/compost) (1.05) 3. LT + IC + 100% N (organic source/compost) (1.02)
Experiment 3: Farmers fields				
	-	-	-	-

Hissar Centre

Pearl millet based production system

4.2.15. Effect of predominant soil and nutrient management practices on soil quality indicators (attributes) and soil quality indices at Hissar centre of AICRPDA

Location description, climate and soil characteristics

Hissar is in western plain Kachchh and part of Kathiawar peninsula, Rajasthan Bagar, north Gujarat Plain and southwestern Punjab plain (AESR 2.3), having a sub-tropical, monsoon type of climate with prolonged hot period from March to October and fairly cool winters. However, extreme temperature fluctuations may occur within a very short-time interval. Total average annual rainfall is around 320 mm with 290 mm in kharif and 40-60 mm in rabi. The average annual rainy days are about 11 with drought occurring once in 5 years. The water availability period is for 7-8 weeks. Usually the cropping period is 11 and 24 weeks in kharif and rabi, respectively. Length of growing period is 60-90 days. The soils of Hissar district are Aridisols (sierozem), deep, loamy desert soils (inclusion of saline phase) where soil reaction is neutral, electrical conductivity is suitable, organic carbon is low and phosphate and potash are medium. Loamy sand to sandy loam soils are also found with calcium carbonate (concretions) layers at depths ranging from within the seeding zone to about 125 cm in patches at various locations. Available water capacity is 120-270 mm m^{-1} and soils are characterized by high infiltration rate and low water holding capacity. Salinity is the serious problem in patches, particularly in irrigated areas. Almost all soils are deficient in nitrogen and zinc, low to medium in phosphorus and high in potassium. Wind erosion is of high severity with moderate loss of topsoil, affecting 26-50% area. Chemical deterioration is also of high severity with moderate effect in 26-50% area. The traditional crops/cropping systems in Kharif are pearl millet, cluster bean, cowpea, moth bean, greengram, blackgram, castor, sesame, and mustard, chickpea, taramira, barely etc, in rabi and the sequence croppings are pearl millet-chickpea/ raya/ fallow, fallow-raya /chickpea, greengram/ cowpea/ moth bean-raya etc. The recommendation domain of the center is dry tracts of Hissar, Sirsa, Fatehbad, Bhiwani, Jhajjar, Mahendergarh, Rewari, Gurgaon, Kandi area of Ambala etc.

In order to study the effect of predominant soil and nutrient management practices on soil quality indicators, and the soil quality indices, the following three experiments and the farmer's fields were chosen at Hissar centre.

- Experiment 1: Integrated nutrient supply for rainfed semiarid tropics
- Experiment 2: Organic farming studies on rainfed mustard

- Experiment 3: Tillage and nutrient management strategies for resource conservation and improving soil quality and productivity of rainfed pearl millet
- Experiment 4: Cropping systems at Farmers fields

4.2.16. Experiment 1: Integrated nutrient supply for rainfed semiarid tropics

In order to reduce the dependence on inorganic fertilizers by using green leaf and compost to build up soil fertility and improve soil health by including a combination of cereals and legumes, an experiment on "integrated nutrient supply for rainfed semiarid tropics" was initiated during the year 1998 in randomized block design with three replications using pearl millet (HHB- 67) and mung bean (Asha) as test crops. In this study, the six integrated nutrient management treatments selected for the soil quality assessment studies were: T1: Control, T2: 100% N (inorganic), T3: 25 kg N (compost), T4: 15 kg N (GLM) + 20 kg N (inorganic), T5: 15 kg N (compost) + 10 kg N (GLM) and T6: 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer. Manuring was done as per treatments to pearl millet crop only, while phosphorus fertilizer was applied common to all the treatments at the recommended level. Soil quality assessment studies were undertaken in this experimental site after the seventh year of the study to evaluate their long-term influence on soil quality.

The data on the long-term influence of integrated nutrient management treatments under alternate strips of pearl millet and mung bean system on soil quality parameters are presented in Tables 58 to 60. Soil pH of the experimental site under different treatments was in slightly alkaline range varying between 7.47 and 7.96. The electrical conductivity of the soils was in the range of 0.13 to 0.16 dS m^{-1} across the treatments. It was observed that both organic carbon as well as available N was conspicuously influenced by the practice of these treatments over years. Organic carbon ranged from 2.33 to 3.22 g kg^{-1} and available N from 131.0 to 172.4 kg ha^{-1} across the management treatments. Application of 15 kg N (compost) + 10 kg N (GLM) recorded significantly highest organic carbon of 3.22 g kg^{-1} while application of 25 kg N (compost) recorded highest available N (172.4 kg ha^{-1}). Available P in these soils varied from 15.8 to 26.2 kg ha^{-1} across the treatments and a significant build up in available P was observed in 15 kg N (compost) + 10 kg N (GLM) (26.2 kg ha^{-1}) which was at par with 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer (26.0 kg ha^{-1}). Available K was observed to be very high varying from 357.6 to 475.5 kg ha^{-1} across the treatments. Significantly highest available K was observed in 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer (475.5 kg ha^{-1}) which was at par with treatments supplied with 25 kg N (compost) and 100% inorganic N (Fig 43).

Table 58: Influence of long-term integrated nutrient supply systems on soil physico-chemical and chemical soil quality parameters under pearl millet + mung bean system in Aridisols of Hissar

SNo	Name of the treatments	pH	EC dS m^{-1}	OC (g kg^{-1})	N	P	K
					(kg ha^{-1})		
1	T1: Control	7.74	0.15	2.33	131.0	15.8	357.6
2	T2: 100% N (inorganic)	7.47	0.14	2.81	163.4	16.3	452.6
3	T3: 25 kg N (compost)	7.81	0.16	2.93	172.4	17.6	457.3
4	T4: 15 kg N (GLM) + 20 kg N (inorganic)	7.96	0.16	3.12	170.4	19.0	409.0
5	T5: 15 kg N (compost) + 10 kg N (GLM)	7.58	0.13	3.22	168.8	26.2	410.2
6	T6: 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer	7.67	0.16	3.19	169.3	26.0	475.5
	CD @ 0.05	0.25	NS	0.40	20.9	3.44	60.5

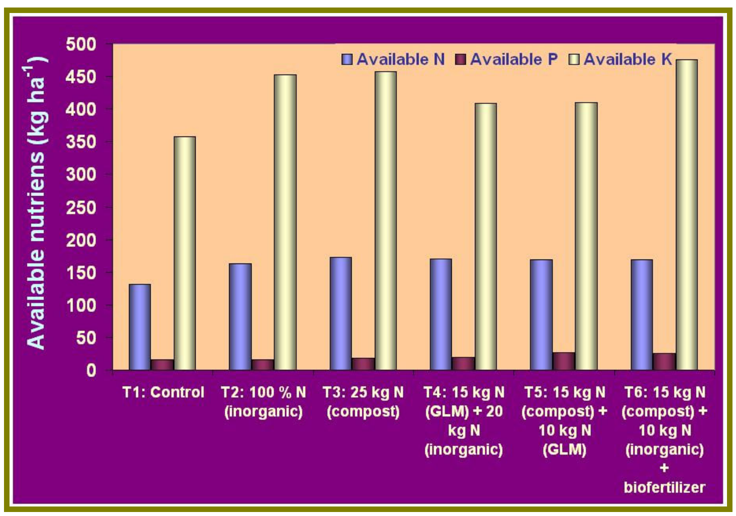


Fig 43: Influence of long-term integrated nutrient supply systems on chemical soil quality parameters (macronutrients) under pearl millet + mung bean system in Aridisols of Hissar

Significant influence of treatments was observed in case of exchangeable Ca and Mg and available S (Fig 44). Exchangeable Ca was slightly high and varied from 4.61 to 6.32 cmol kg^{-1} and exchangeable Mg varied from 0.76 to 1.04 cmol kg^{-1} across the treatments. Significantly highest amounts of both exchangeable Ca (6.32 cmol kg^{-1}) and Mg (1.04 cmol kg^{-1}) were observed under application of 15 kg N (GLM) + 20 kg N (inorganic). Available S, varying from 18.1 to 28.5 kg ha^{-1}, was significantly highest under 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer (28.5

kg ha^{-1}). Among the micronutrients, DTPA extractable Zn, Cu and Mn contents varying from 0.78 to 1.32, 0.43 to 0.70 and 6.85 to 8.41 µg g^{-1} of soil respectively showed a significant difference due to the INM treatments. The treatments showing significantly highest contents of these micronutrients were: 25 kg N (compost) for Zn (1.32 µg g^{-1}), 100% N (inorganic) for Cu (0.70 µg g^{-1}) and 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer for Mn (8.41 µg g^{-1}). On the other hand, it was observed that the DTPA extractable Fe and DTPA sorbitol extractable B were not significantly influenced by the management treatments (Fig 45).

Table 59: Influence of long-term integrated nutrient supply systems on soil chemical soil quality parameters under pearl millet + mung bean system in Aridisols of Hissar

SNo	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		cmol kg^{-1}		(kg ha^{-1})	µg g^{-1}				
1	T1: Control	4.61	0.76	18.1	0.78	2.51	0.43	6.85	0.88
2	T2: 100% N (inorganic)	6.11	1.01	23.3	1.16	2.58	0.70	8.32	1.02
3	T3: 25 kg N (compost)	5.65	0.93	25.7	1.32	2.69	0.52	7.16	1.06
4	T4: 15 kg N (GLM) + 20 kg N (inorganic)	6.32	1.04	24.1	1.23	2.60	0.48	7.50	1.07
5	15 kg N (compost) + 10 kg N (GLM)	5.26	0.80	26.0	1.27	2.61	0.55	7.39	1.05
6	T6: 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer	5.63	0.91	28.5	1.26	2.74	0.54	8.41	1.11
	CD @ 0.05	0.98	0.14	5.70	0.11	NS	0.12	0.75	NS

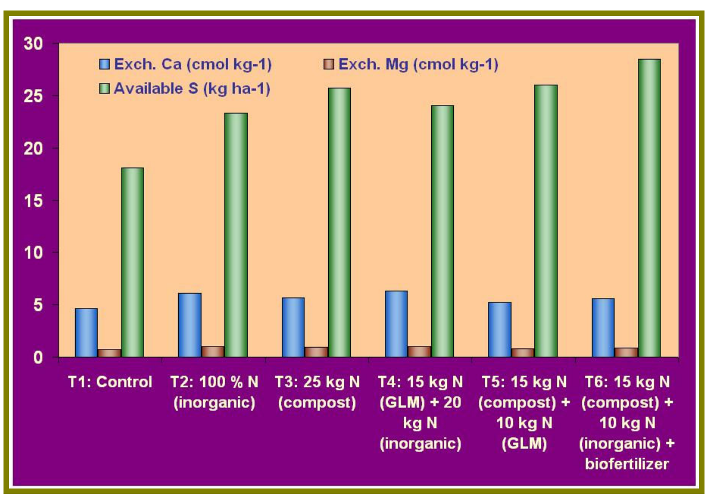


Fig 44: Influence of long-term integrated nutrient supply systems on chemical soil quality parameters (secondary nutrients) under pearl millet + mung bean system in Aridisols of Hissar

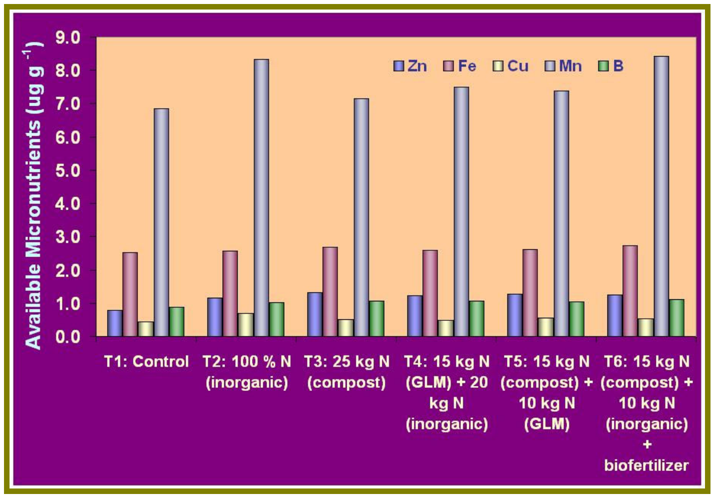


Fig 45: Influence of long-term integrated nutrient supply systems on chemical soil quality parameters (micronutrients) under pearl millet + mung bean system in Aridisols of Hissar

The influence of the INM treatments on both the biological soil quality parameters studied viz., dehydrogenase assay, microbial biomass carbon and labile carbon were quite conspicuous (Fig 46). It was observed that DHA was significantly highest under the application of 25 kg N (compost) (5.76 (µg TPF $hr^{-1}g^{-1}$) and MBC under the application of 15 kg N (GLM) + 20 kg N (inorganic) (179.7 µg g^{-1} of soil) both of which were at par with the application of 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer. Similar to DHA, application of 25 kg N (compost) recorded significantly highest labile carbon content of 235.9 µg g^{-1} of soil. The physical soil quality parameters viz., bulk density and mean weight diameters, were conspicuously influenced by the INM treatments. Bulk density varied from 1.23 to 1.33 Mg m^{-3} while mean weight diameter varied from 0.12 to 0.16 mm across the nutrient management treatments. Significantly better soil physical conditions were observed under application of 25 kg N (compost) (Fig 47).

Table 60: Influence of long-term integrated nutrient supply systems on soil biological and physical soil quality parameters under pearl millet + mung bean system in Aridisols of Hissar

SNo	Name of the treatments	DHA (µg TPF $hr^{-1}g^{-1}$)	MBC (µg g^{-1} of soil)	LC (µg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	T1: Control	4.44	134.5	189.5	1.33	0.12
2	T2: 100% N (inorganic)	4.87	142.8	211.4	1.29	0.12
3	T3: 25 kg N (compost)	5.76	160.4	235.9	1.23	0.16
4	T4: 15 kg N (GLM) + 20 kg N (inorganic)	5.46	179.7	222.8	1.26	0.16
5	15 kg N (compost) + 10 kg N (GLM)	5.02	164.7	228.4	1.23	0.15
6	T6: 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer	5.70	168.7	220.0	1.26	0.15
	CD @ 0.05	0.83	20.6	24.7	0.05	0.03

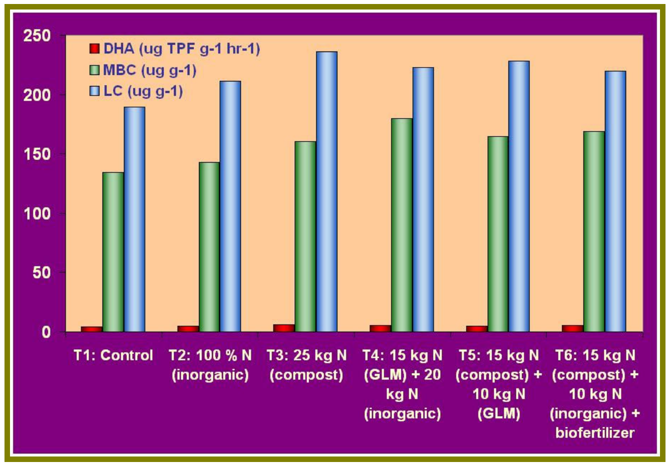


Fig 46: Influence of long-term integrated nutrient supply systems on biological soil quality parameters under pearl millet + mung bean system in Aridisols of Hissar

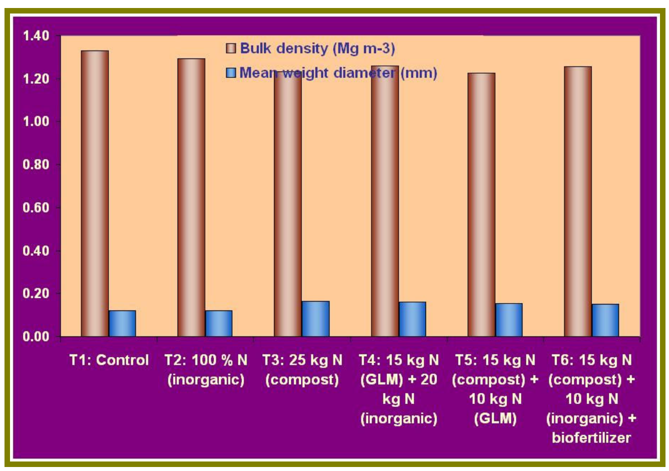


Fig 47: Influence of long-term integrated nutrient supply systems on physical soil quality parameters under pearl millet + mung bean system in Aridisols of Hissar

4.2.16.1. Key indicators and soil quality assessment

4.2.16.2. Results of principal component analysis

The long-term influence of integrated nutrient management treatments practiced under alternate strips of pearl millet and mung bean system on 19 soil quality indices has been studied and it was observed that out of 19 soil quality parameters, three variables viz., EC, available Fe and available B were not significantly influenced by the management treatments and were dropped from the

PCA. In the PCA of 16 variables, four PCs had eigen values >1 and explained 80.3% variance in the data set (Table 61). In PC1, available N and Zn were qualified as the highly weighted variables while in PC2 and PC3, each one variable viz., available Cu and pH qualified as the highly weighted variables respectively. In PC4, two variables viz., available K and DHA were highly weighted. The correlation matrix run for the variables qualified under PC1 and PC4 revealed a significant correlation between available N and Zn while the correlation between available K and DHA, though well correlated, was not significant (Table 62). Anyhow, considering their importance, all the variables viz., pH, available N, K, Zn, Cu and dehydrogenase were retained in the minimum data set and considered as the key indicators for pearl millet -mung bean system in Aridisols of Hissar.

Table 61: Principal component analysis of soil quality parameters as influenced by different INM treatments under pearl millet and mung bean system

	PC1	PC2	PC3	PC4
Total Eigen values	7.338	2.537	1.933	1.038
% of Variance	45.86	15.85	12.08	6.49
Cumulative %	45.86	61.72	73.80	80.29
Eigen Vectors				
pH	0.132	-0.518	**0.724**	0.291
OC	0.822	-0.032	-0.137	0.123
N	**0.906**	0.091	-0.001	0.089
P	0.589	-0.219	-0.584	0.085
K	0.664	0.457	-0.010	**0.479**
Ca	0.583	0.346	0.576	-0.188
Mg	0.418	0.482	0.616	-0.294
S	0.763	-0.045	-0.384	-0.057
Zn	**0.944**	0.014	-0.048	-0.094
Cu	0.256	**0.853**	-0.085	-0.289
Mn	0.467	0.639	-0.159	0.270
DHA	0.705	-0.105	0.272	**0.465**
MBC	0.731	-0.374	0.057	-0.190
LC	0.816	-0.244	0.055	-0.092
BD	-0.762	0.213	0.227	0.296
MWD	0.698	-0.506	0.151	-0.234

Table 62: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs		
PC1	N	Zn
N	1.00	0.842**
Zn	0.842**	1.00
MBC		
Correlation sum	1.842	1.842
PC2	K	DHA
K	1.00	0.639**
DHA	0.639**	1.00
Correlation sum	1.639	1.639

**correlation is significant at P = 0.01 level

4.2.16.3. Soil quality indices

Soil quality indices were computed using six key soil quality indicators viz., pH, available N, K, Zn, Cu and dehydrogenase activity. The soil quality indices varied from 1.11 to 1.52 across the management treatments practiced for pearl millet and mung bean system (Table 63 & Fig 48). For simple understanding, the soil quality indices were reduced to a scale of one, termed as 'relative soil quality indices' (RSQI) which varied between 0.70 and 0.97. From the data, it was observed that the application of 25 kg N compost showed the highest soil quality index of 1.52 and its performance was observed to be almost at par with all the treatments except control. Irrespective of their statistical significance, the relative order of performance in influencing soil quality in terms of SQI was: T3: 25 kg N (compost) (1.52) > T6: 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer (1.49) > T5: 15 kg N (compost) + 10 kg N (GLM) (1.47) > T4: 15 kg N (GLM) + 20 kg N (inorganic) (1.46) > T2: 100 % N (inorganic) (1.45) and T1: Control (1.11**).** The average percent contribution of key indicators towards soil quality indices was: available N (35%), available Zn (35%), available Cu (10%), pH (10%), available K (5%) and dehydrogenase assay (5%) (Fig 49).

Table 63: Soil quality indices and relative soil quality indices of the management treatments

Treatments	SQI	RSQI
T1: Control	1.11	0.70
T2: 100 % N (inorganic)	1.45	0.92
T3: 25 kg N (compost)	1.52	0.97
T4: 15 kg N (GLM) + 20 kg N (inorganic)	1.46	0.93
T5: 15 kg N (compost) + 10 kg N (GLM)	1.47	0.94
T6: 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer	1.49	0.95
CD @ 0.05	0.09	0.06

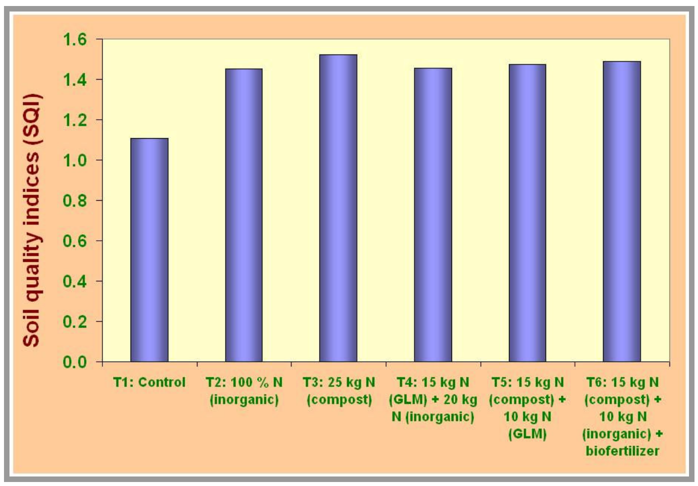


Fig 48: Soil quality indices of different integrated nutrient management treatments practiced under pearl millet -mung bean system in Aridisols of Hissar

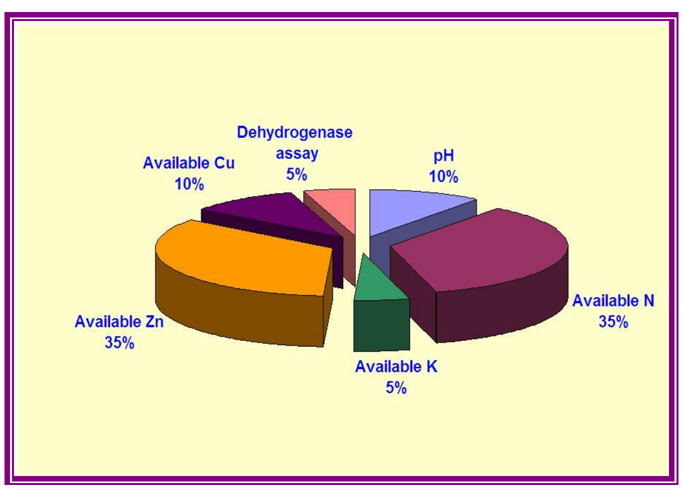


Fig 49: Percent contribution of key indicators towards soil quality indices under pearl millet mung bean system in Aridisols of Hissar

4.2.17. Experiment 2: Organic farming studies on rainfed mustard

Indiscriminate use of inorganic fertilizers in crop production leads to pollution of soil and ground water. Soil health including flora and fauna, animals and human beings are thus adversely affected. As fertilizer use is becoming popular in dryland agriculture that may also pollute soil environment as in case of irrigated agriculture. Organic farming by using organic sources and bio-fertilizers is the only answer to combat this problem. Hence, in order to compare the effect of different organic sources on the yield of succeeding crop, to study the effect of organic manuring on soil properties and to compare the yield and economics of mustard as affected by organic and inorganic fertilizers, an experiment on organic farming in rainfed mustard has been initiated. This experiment was initiated during the year 1997-98 in a split plot design using Diancha (Local) and Cowpea (CS-88) as kharif crops and mustard (RH-30) as rabi crop. Samples from the experimental plots were collected after 7^{th} year of study and were analyzed for various soil quality parameters.

The physico-chemical soil quality parameters viz., pH and EC varied from 7.62 to 7.67 and 0.15 to 0.16 dS m^{-1} across the management treatments and were not significantly influenced (Table 64). Organic carbon as well as available N in the soils varied from 2.61 to 3.22 g kg^{-1} and 136.4 to 167.0 kg ha^{-1} across the treatments. Conspicuous influence of the manurial treatments was observed on available P and K and the contents of available P were medium varying from 14.4 to 25.9 kg ha^{-1} while available K was very high ranging from 384.7 to 476.5 kg ha^{-1} across the treatments. Application of cowpea green manure (40 DAS) recorded significantly highest available P (25.9 kg ha^{-1}), which was at par with other manurial treatments. In case of available K, application of FYM @ 4 t ha^{-1} significantly recorded highest available K (476.5 kg ha^{-1}) which was at par with other manurial treatments (Fig 50).

Table 64: Influence of manurial treatments on soil physico-chemical and chemical soil quality parameters under mustard system in Aridisols of Hissar

SNo	Name of the treatments	pH	EC dS m^{-1}	OC (g kg^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
1	T1: Control	7.62	0.16	2.61	136.4	14.4	384.7
2	T2: FYM (4 t ha^{-1})	7.62	0.16	3.07	165.7	21.6	476.5
3	T3: Vermiculture (4 tha^{-1})	7.67	0.16	3.07	167.0	21.4	444.5
4	T4: Diancha Green manure (40 DAS)	7.62	0.15	2.93	160.2	20.3	454.7
5	T5: Cowpea green manure (40 DAS)	7.67	0.15	3.22	166.7	25.9	472.0
	CD @ 0.05	NS	NS	0.25	17.4	5.98	58.5

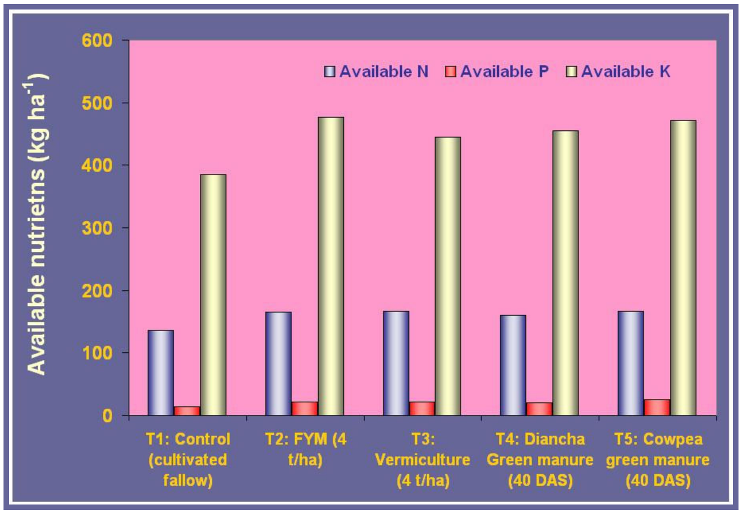


Fig 50: Influence of manurial treatments on chemical soil quality parameters (macronutrients) under mustard system in Aridisols of Hissar

The influence of the manurial treatments was quite conspicuous on all secondary nutrients except exchangeable Ca and on all micronutrients except available B (Table 65 & Figs 51, 52). However, irrespective of their significance, exchangeable Ca content varied between 4.34 and 5.89 cmol kg^{-1} while available B ranged from 0.96 to 1.17 µg g^{-1} across the manurial treatments. Application of cowpea green manure (40 DAS) recorded significantly highest exchangeable Mg (0.98 cmol kg^{-1}) as well as available S (29.0 kg ha^{-1}), which was at par with application of Vermiculture (4 tha^{-1}). Among the micronutrients, available Zn, Fe, Cu and Mn contents varied from 1.04 to 1.61, 3.51 to 4.80, 0.067 to 1.68 and 0.96 to 1.17 µg g^{-1} respectively across the manurial treatments. Significantly highest available Zn (1.61 µg g^{-1}), Fe (4.80 µg g^{-1}) and Mn (10.6 µg g^{-1}) contents were observed under application of FYM (4 t ha^{-1}) while the highest available Cu content of 1.68 µg g^{-1} was observed under application of Vermiculture (4 tha^{-1}).

Table 65: Influence of manurial treatments on chemical soil quality parameters under mustard system in Aridisols of Hissar

SNo	Name of the treatments	Ca	Mg	S (kg ha^{-1})	Zn	Fe	Cu	Mn	B
		cmol kg^{-1}			µg g^{-1}				
1	T1: Control	4.34	0.72	18.5	1.04	3.51	0.67	7.42	0.96
2	T2: FYM (4 t ha^{-1})	5.79	0.84	33.7	1.61	4.80	1.28	10.6	1.02
3	T3: Vermiculture (4 tha^{-1})	5.89	0.96	28.1	1.45	3.73	1.68	8.51	1.17
4	T4: Diancha Green manure (40 DAS)	5.19	0.80	20.8	1.36	3.65	0.71	8.21	1.00
5	T5: Cowpea green manure (40 DAS)	5.79	0.98	29.0	1.51	3.64	1.16	9.87	1.02
	CD @ 0.05	NS	0.08	6.73	0.11	0.84	0.20	1.05	NS

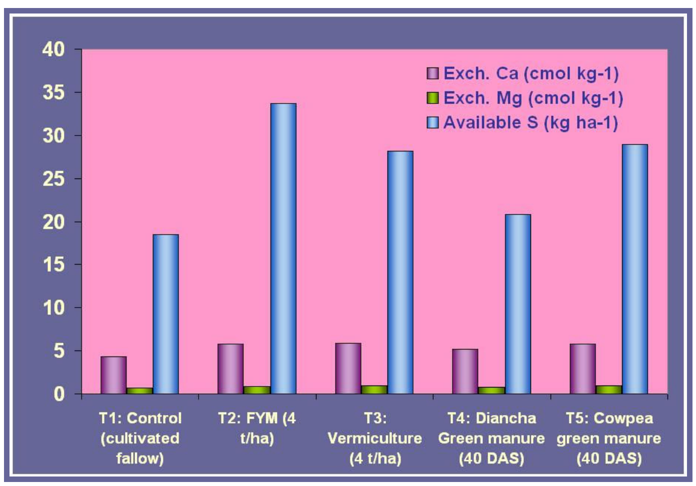


Fig 51: Influence of manurial treatments on chemical soil quality parameters (secondary nutrients) under mustard system in Aridisols of Hissar

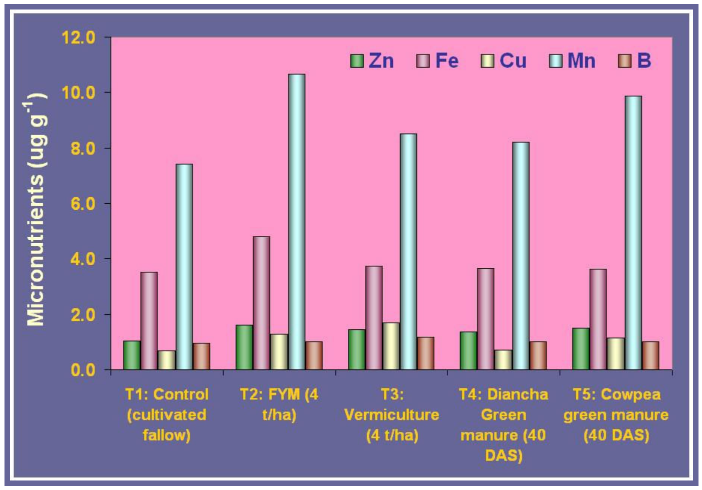


Fig 52: Influence of manurial treatments on chemical soil quality parameters (micronutrients) under mustard system in Aridisols of Hissar

The study revealed a significant influence of the manurial treatments on all the biological soil quality parameters (Table 66 & Figs 53, 54). Dehydrogenase activity in the soils was recorded to the extent of 5.55 to 7.62 µg TPF $hr^{-1}g^{-1}$ as influenced by the management treatments, while microbial biomass carbon and labile carbon were recorded to the extent of 130.8 to 196.7 and 219.5 to 271.0 µg g^{-1} of soil respectively. It was observed that, of all the manurial treatments, application of FYM @ 4 t ha^{-1} recorded significantly highest contents of DHA activity (7.62 µg TPF $hr^{-1}g^{-1}$), microbial biomass carbon (196.7 µg g^{-1} of soil) as well as labile carbon (271.0 µg g^{-1} of soil). Of the physical soil quality parameters, bulk density was conspicuously influenced by the manurial treatments and varied from 1.22 to 1.33 Mg m^{-3}. However, irrespective of the significance, mean weight diameter varied from 0.13 to 0.16 mm across the treatments.

Table 66: Influence of manurial treatments on biological and physical soil quality parameters under mustard system in Aridisols of Hissar

SNo	Name of the treatments	DHA (µg TPF $hr^{-1}g^{-1}$)	MBC (µg g^{-1} of soil)	LC (µg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	T1: Control	5.55	130.8	219.5	1.33	0.13
2	T2: FYM (4 t ha^{-1})	7.62	196.7	271.0	1.22	0.16
3	T3: Vermiculture (4 tha^{-1})	6.21	158.5	247.0	1.25	0.15
4	T4: Diancha Green manure (40 DAS)	6.05	172.8	240.7	1.23	0.16
5	T5: Cowpea green manure (40 DAS)	7.04	167.5	241.2	1.23	0.14
	CD @ 0.05	0.72	20.7	26.3	0.05	NS

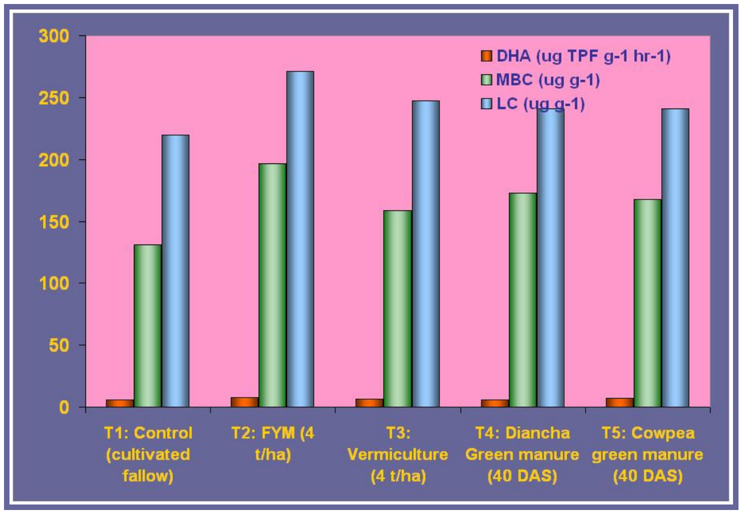


Fig 53: Influence of manurial treatments on biological soil quality parameters under mustard system in Aridisols of Hissar

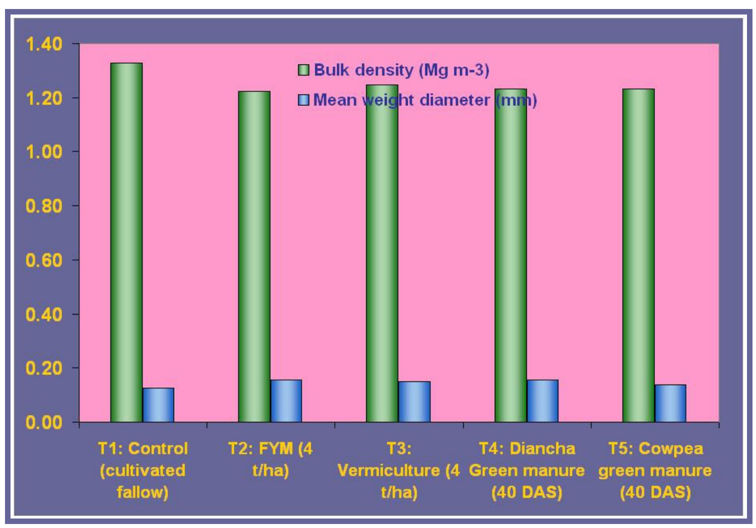


Fig 54: Influence of manurial treatments on physical soil quality parameters under mustard system in Aridisols of Hissar

4.2.17.1. Key indicators and soil quality assessment

4.2.17.2. Results of principal component analysis

The long-term influence of manurial treatments practiced under mustard system on 19 soil quality indices has been statistically analyzed and it was observed that out of 19 soil quality parameters, five variables viz., pH, EC, exchangeable Ca, available B and MWD were insignificant and hence were dropped from further PCA analysis. In the PCA of 14 variables, three PCs had eigen values >1 and explained 79.7% variance in the data set (Table 67). In PC1, and PC3, only single variables viz., available Zn and available P were qualified as the highly weighted variables respectively while in PC2, two variables viz., exchangeable Mg and available Fe were the highly weighted variables. The correlation matrix run for the variables qualified under PC2 revealed no significant relation between the variables and hence both of them were considered for final MDS (Table 68). On the whole, surprisingly very few indicators viz., available P, exchangeable Mg, and available Zn & Fe were qualified for the final MDS and termed as the key indicators for mustard system in Aridisols of Hissar and these indicators were used for computing the soil quality indices.

Table 67: Principal component analysis of soil quality parameters as influenced by different manurial treatments under mustard system in Aridisols of Hissar

	PC1	PC2	PC3
Total Eigen values	8.534	1.590	1.032
% of Variance	60.95	11.36	7.37
Cumulative %	60.95	72.31	79.69
Eigen Vectors			
OC	0.824	-0.320	0.243
N	0.801	-0.193	-0.192
P	0.759	-0.386	**-0.425**
K	0.731	-0.137	-0.59
Mg	0.677	**-0.645**	0.197
S	0.839	0.073	0.289
Zn	**0.963**	0.032	0.078
Fe	0.568	**0.620**	-0.252
Cu	0.673	-0.271	0.289
Mn	0.846	0.281	0.016
DHA	0.834	0.283	0.105
MBC	0.812	0.304	-0.095
LC	0.753	0.387	0.325
BD	-0.774	0.034	0.082

Table 68: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs	Mg	Fe
Mg	1.00	-0.075
Fe	-0.075	1.00
Correlation sum	-1.075	-1.075

4.2.17.3. Soil quality indices

Soil quality indices were computed using four key soil quality indicators viz., available P, exchangeable Mg, and available Zn & Fe. The soil quality indices varied from 0.71 to 1.04 across the manurial treatments practiced for mustard system (Table 69 & Fig 55). For simple understanding, the soil quality indices, were reduced to a scale of one, termed as 'relative soil quality indices' (RSQI) which varied between 0.65 and 0.95. Among all the manurial treatments practiced, the application of FYM @ 4 t ha^{-1} showed the highest soil quality index of 1.04 and its performance was observed to be almost at par with all the treatments. Irrespective of their statistical significance, the relative order of performance in influencing soil quality in terms of SQI was: T2: FYM (4 t ha^{-1}) (1.04) > T5: Cowpea green manure (40 DAS) (1.00) > T3: Vermiculture (4 tha^{-1}) (0.95) > T4: Diancha Green manure (40 DAS) (0.89) > T1: Control (0.71). The average percent contribution of key indicators towards soil quality indices was: available Zn (63%), exchangeable Mg (13%), available Fe (11%) and available P (7%) (Fig 56).

Table 69: Soil quality indices and relative soil quality indices of the management treatments

Sno	Treatments	SQI	RSQI
1	T1: Control	0.71	0.65
2	T2: FYM (4 t ha^{-1})	1.04	0.95
3	T3: Vermiculture (4 tha^{-1})	0.95	0.88
4	T4: Diancha Green manure (40 DAS)	0.89	0.82
5	T5: Cowpea green manure (40 DAS)	1.00	0.92
	CD (0.05)	0.06	0.05

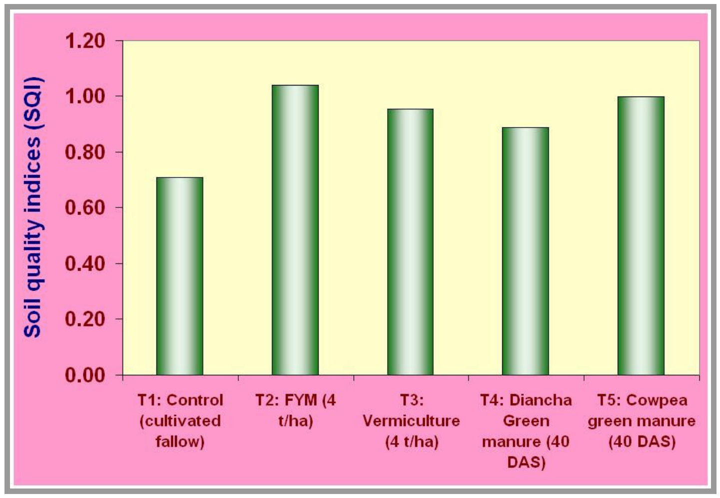


Fig 55: Soil quality indices of different manurial treatments practiced under mustard system in Aridisols of Hissar

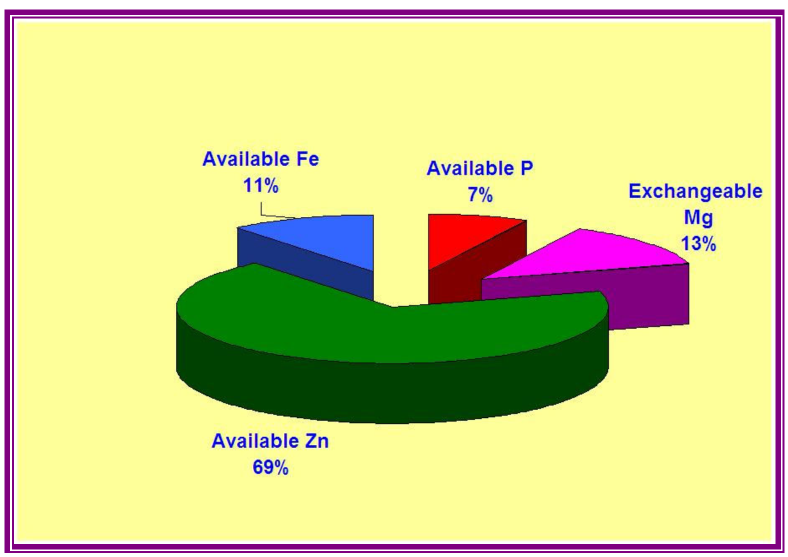


Fig 56: Percent contribution of key indicators towards soil quality indices under mustard system in Aridisols of Hissar

4.2.18. Experiment 3: Tillage and nutrient management strategies for resource conservation and improving soil quality and productivity of rainfed pearl millet

Excessive tillage operations demand not only more of energy and cost but also deteriorate the soil health. The use of inorganic fertilizers is costly and not eco-friendly. Minimum tillage and organic farming reduces the cost and energy requirement and improves the soil and environmental health. Hence, in order to i) work out the appropriate practices for the success of minimum till systems, ii) assess the impact of low till systems on crop yields, iii) study the long term impact of low till systems on soil quality and to iv) quantify the energy savings with low till systems, an experiment was initiated with tillage and nutrient management strategies for resource conservation and improving soil quality and productivity using rainfed pearl millet as test crop. The experiment was initiated during the year 2001 with five tillage treatments and six nutrient management treatments out of which only three tillage and three nutrient management treatments have been selected for soil quality assessment studies. The main treatments included conventional tillage (CT) + two intercultures (IC); Low tillage (LT) + Two IC and Low tillage + Weedicide (Wd) + One IC. The sub treatments included 100% N (organic source/compost); 50% N (organic) + 50 % inorganic source) and 100% N (inorganic source). The experiment was laid in split plot design with three replications using pearl millet as test crop. Soil quality assessment studies were undertaken after four years of experimentation and the results are interpreted as follows.

Soil reaction varied from 7.32 to 7.87 and was not influenced by the soil nutrient management treatments practiced (Table 70). Electrical conductivity of the soils ranged from 0.11 to 0.17 across the management treatments and no influence of tillage and the nutrient management treatments on EC was observed. Similarly organic carbon content was very low varying between 2.50 to 3.15 g kg^{-1} and a conspicuous influence of the tillage was observed on organic carbon content while the nutrient management treatments did not show any influence. Among the tillage practices, low tillage + two interculture treatments recorded significantly highest organic carbon (2.95 g kg^{-1}) while the lowest was under conventional tillage practice. Among the chemical soil quality parameters, available N was observed to be very low ranging from 153.7 to 187.3 kg ha^{-1} across the management treatments. The tillage practices followed did not show any significant influence on available N content but the nutrient management practices showed a significant influence of which application of 100% N through organic source recorded the highest value of 179.1 kg ha^{-1} followed by 50% N (organic) + 50 % (inorganic source) which recorded available N to the extent of 16.02 kg ha^{-1}. The interaction effects of both tillage as well as the nutrient management practices also did not show a conspicuous influence on available N. Available P in the soils was found to be medium varying from 17.2 to 23.1 kg ha^{-1} and was neither influenced by tillage or nutrient management practices nor by their interaction effects. Available K status in the soils was observed to be quite high ranging from 301.7 to 471.3 kg ha^{-1} across the management treatments. The main treatment i.e. tillage practices did not show any conspicuous effect on available K but the sub treatments i.e. nutrient management practices showed a significant effect (Fig 57).

Table 70: Influence of tillage and nutrient management treatments on physico-chemical and chemical soil quality parameters under pearl millet system in Aridisols of Hissar

SNo	Name of the treatments	pH	EC dS m^{-1}	OC (g kg^{-1})	N	P	K
						(kg ha^{-1})	
1	CT + Two IC + 100% N (organic source/compost)	7.54	0.11	2.60	187.3	17.2	301.7
2	CT + Two IC + 50% N (organic) + 50 % inorganic source)	7.72	0.13	2.52	180.2	17.6	329.7
3	CT + two IC + 100% N (inorganic source)	7.45	0.13	2.50	170.5	23.1	471.3
4	LT + Two IC + 100% N (organic source/compost)	7.60	0.17	3.15	183.1	19.0	351.2
5	LT + Two IC + 50% N (organic) + 50 % inorganic source)	7.50	0.12	3.09	155.3	18.0	416.2
6	LT + IC + 100% N (inorganic source)	7.32	0.11	2.60	153.7	17.8	391.8
7	LT + Weedicide + One IC + 100% N (organic source/compost)	7.65	0.14	2.96	167.1	17.4	335.0
8	LT + Weedicide + One IC + 50% N (organic) + 50 % inorganic source)	7.87	0.12	2.77	154.1	16.8	413.9
9	LT + Weedicide + One IC + 100% N (inorganic source)	7.82	0.13	2.73	155.5	19.0	461.5
	CD @ 0.05						
	Between two main treatment means	NS	NS	0.20	NS	NS	NS
	Between two sub treatment means	NS	NS	NS	6.14	NS	26.4
	Between two sub treatment means at same main treatments	NS	0.03	NS	NS	NS	45.8
	Between two main treatment means at same or different sub treatments	NS	0.03	NS	NS	NS	49.6

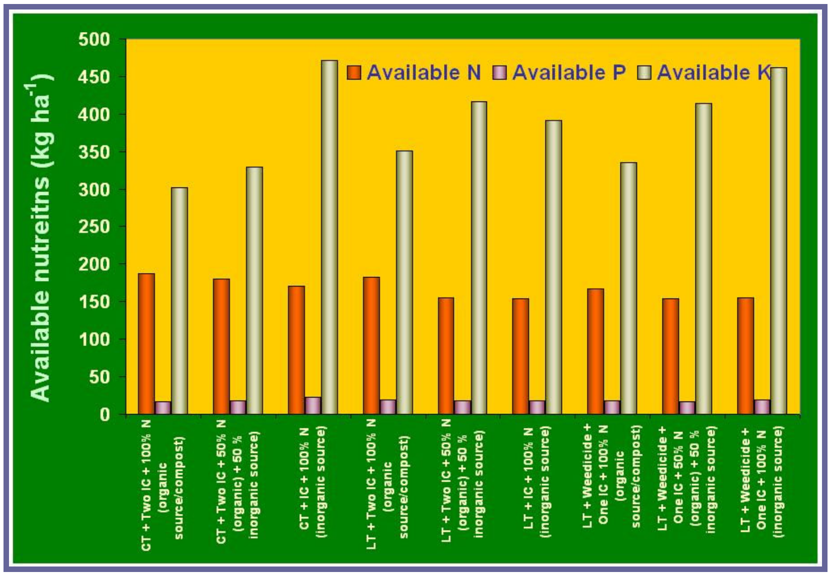


Fig 57: Influence of tillage and nutrient management treatments on chemical soil quality parameters (macronutrients) under pearl millet system in Aridisols of Hissar

Exchangeable Ca in the soils varied from 3.43 to 4.77 cmol kg^{-1} while exchangeable Mg varied from 0.63 to 0.80 cmol kg^{-1} across the management treatments (Table 71 & Fig 58). Tillage showed a conspicuous influence on both Ca and Mg while the nutrient management treatments did not show any influence. On the other hand, available S ranging from 14.7 to 32.7 kg ha^{-1} was significantly influenced both by the tillage and nutrient management treatments but not by their interaction effects. Either one or all the tillage and nutrient management treatments significantly influenced the micronutrients, except available Fe, which was neither influenced by the main or sub treatments or their interaction effects. Available Zn ranged from 1.03 to 1.61 µg g^{-1} across the management treatments. Among the tillage practices followed, the practice of conventional tillage + two interculture showed significantly highest amount of Zn (1.40 µg g^{-1}) while among the nutrient management treatments, it was the 100% organic treatment which recorded the highest Zn of 1.36 µg g^{-1} followed by 50% N by organic and 50% N by inorganic source. But the interaction effects of these treatments did not have any significant influence on available Zn. Available Fe, though not significantly influenced by any of the management practices, was observed to range from 2.32 to 2.84 µg g^{-1} across the treatments. Available Cu varied from 0.32 to 0.54 µg g^{-1} across the treatments and was recorded highest under conventional tillage practices with two interculture treatments (0.46 µg g^{-1}). Available Mn in these soils varied from 6.83 to 13.6 µg g^{-1} across the management treatments and conventional tillage practice + 2 interculture treatments recorded highest available Mn (11.85 µg g^{-1}) while it was the application of 50% N in organic form and 50% N in inorganic form which recorded highest available Mn (10.57 µg g^{-1}). Among all the nutrient management treatments, significantly highest contents of both available Cu (0.54 μg g^{-1}) and Mn (13.6 μg g^{-1}) were observed under application of conventional tillage + two interculture + 100% N (inorganic source). Both tillage as well as nutrient management treatments alone did not significantly influence the available B while their interactive effects showed a conspicuous influence. Practice of low tillage + two interculture operations + 100% N (organic source/compost) recorded significantly highest available B (0.86 μg g^{-1}) while the practice of conventional tillage + two interculture operations + 100% N (organic source/compost) recorded the lowest (0.57 μg g^{-1}).

Table 71: Influence of tillage and nutrient management treatments on chemical soil quality parameters under pearl millet system in Aridisols of Hissar

SNo	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		cmol kg^{-1}		(kg ha^{-1})	μg g^{-1}				
1	CT + Two IC + 100% N (organic source/compost)	3.77	0.79	18.5	1.61	2.52	0.42	12.1	0.57
2	CT + Two IC + 50% N (organic) + 50 % inorganic source)	3.74	0.74	14.7	1.31	2.51	0.42	9.83	0.70
3	CT + two IC + 100% N (inorganic source)	3.43	0.80	18.5	1.28	2.50	0.54	13.6	0.74
4	LT + Two IC + 100% N (organic source/compost)	4.77	0.63	15.9	1.30	2.45	0.46	6.83	0.86
5	LT + Two IC + 50% N (organic) + 50 % inorganic source)	4.28	0.76	23.7	1.26	2.40	0.41	8.82	0.73
6	LT + IC + 100% N (inorganic source)	4.11	0.70	26.5	1.03	2.33	0.38	8.57	0.74
7	LT + Weedicide + One IC + 100% N (organic source/compost)	4.09	0.72	22.7	1.18	2.84	0.38	7.74	0.68
8	LT + Weedicide + One IC + 50% N (organic) + 50 % inorganic source)	3.60	0.75	27.2	1.14	2.75	0.36	13.1	0.75
9	LT + Weedicide + One IC + 100% N (inorganic source)	4.14	0.64	32.7	0.96	2.32	0.32	8.41	0.58
	CD @ 0.05								
	Between two main treatment means	0.53	0.05	6.09	0.04	NS	0.04	0.67	NS
	Between two sub treatment means	NS	NS	3.69	0.08	NS	NS	0.55	NS
	Between two sub treatment means at same main treatments	NS	0.06	NS	NS	NS	0.06	0.95	0.13
	Between two main treatment means at same or different sub treatments	NS	0.07	NS	NS	NS	0.06	0.94	0.17

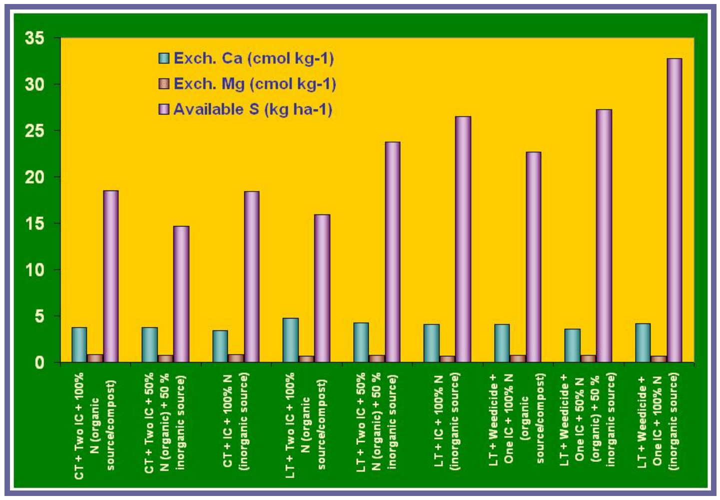


Fig 58: Influence of tillage and nutrient management treatments on chemical soil quality parameters (secondary nutrients) under pearl millet system in Aridisols of Hissar

Among the biological soil quality parameters, dehydrogenase activity was significantly influenced by the nutrient management practices but not tillage and was observed to range from 3.68 to 4.73 μg TPF $hr^{-1}g^{-1}$ across the management treatments (Table 72 & Fig 59). Among the nutrient management treatment application of 100% organic sources recorded significantly highest DHA (4.56 μg TPF $hr^{-1}g^{-1}$) followed by the other two treatments. Labile carbon was not significantly influenced by any of the management treatments and varied from 218.4 to 243.8 μg g^{-1} of soil respectively across the management treatments. However, microbial biomass carbon, varying from 97.3 to 169.1 μg g^{-1} of soil was conspicuously influenced by all the management treatments. Among the tillage treatments, the practice of low tillage + two intercultural operations recorded significantly highest microbial biomass activity (146.9 μg g^{-1} of soil) while among the nutrient management treatments, application of 50% N (organic) and 50% N through inorganic sources recorded highest MBC of 138.2 μg g^{-1} of soil. Among all the treatments, practice of low tillage + two intercultural practices + 50% N (organic) + 50 % through inorganic source recorded significantly highest MBC of 169.1 μg g^{-1} of soil. Among the physical soil quality parameters studied, bulk density, varying from 1.26 to 1.30 Mg m^{-3} across the treatments, was found to be lowest with application of 100% organic sources, while the mean weight diameter varying from 0.12 to 0.16 mm across the treatments was neither influenced by the sole tillage or nutrient management practices nor their interaction effects (Fig 60).

Table 72: Influence of tillage and nutrient management treatments on biological and physical soil quality parameters under pearl millet system in Aridisols of Hissar

SNo	Name of the treatments	DHA (µg TPF $hr^{-1}g^{-1}$)	MBC (µg g^{-1} of soil)	LC (µg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	CT + Two IC + 100% N (organic source/compost)	4.24	141.7	229.4	1.25	0.14
2	CT + Two IC + 50% N (organic) + 50 % inorganic source)	3.76	135.4	219.7	1.29	0.14
3	CT + Two IC + 100% N (inorganic source)	4.21	112.3	221.3	1.30	0.12
4	LT + Two IC + 100% N (organic source/compost)	4.73	151.1	239.5	1.26	0.15
5	LT + Two IC + 50% N (organic) + 50 % inorganic source)	3.92	169.1	218.4	1.28	0.12
6	LT + IC + 100% N (inorganic source)	3.68	120.7	240.4	1.26	0.13
7	LT + Weedicide + One IC + 100% N (organic source/compost)	4.70	97.3	243.8	1.26	0.16
8	LT + Weedicide + One IC + 50% N (organic) + 50 % inorganic source)	4.24	110.1	233.4	1.28	0.12
9	LT + Weedicide + One IC + 100% N (inorganic source)	3.85	110.3	237.0	1.30	0.13
	CD @ 0.05					
	Between two main treatment means	NS	19.4	NS	NS	NS
	Between two sub treatment means	0.33	14.6	NS	0.03	NS
	Between two sub treatment means at same main treatments	NS	25.4	NS	NS	NS
	Between two main treatment means at same or different sub treatments	NS	25.7	NS	NS	NS

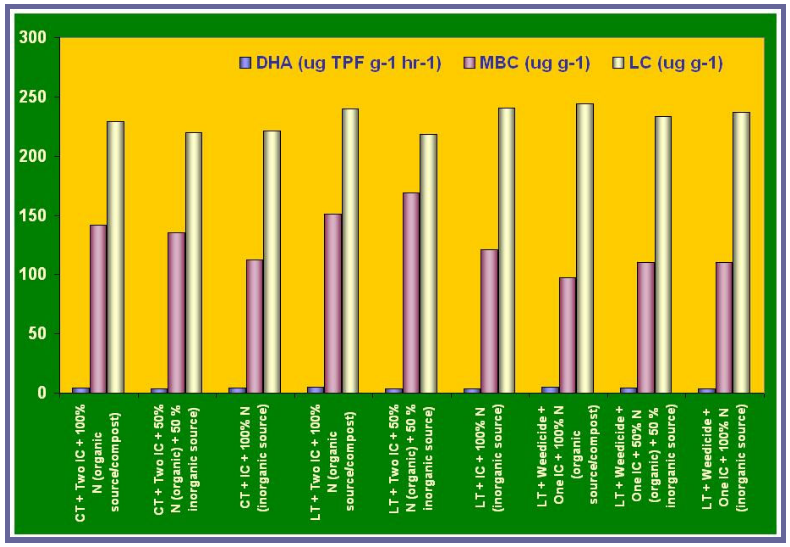


Fig 59: Influence of tillage and nutrient management treatments on biological soil quality parameters under pearl millet system in Aridisols of Hissar

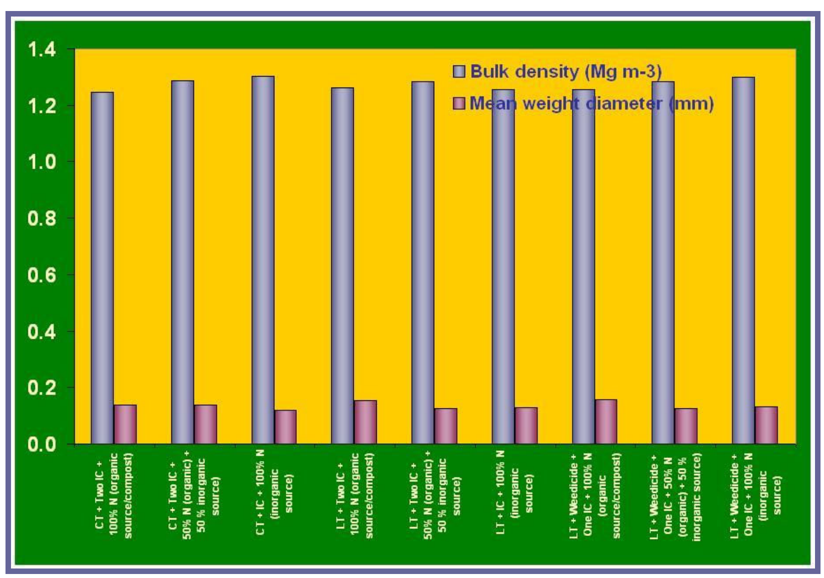


Fig 60: Influence of tillage and nutrient management treatments on physical soil quality parameters under pearl millet system in Aridisols of Hissar

4.2.18.1. Key indicators and soil quality assessment

4.2.18.2. Results of principal component analysis

The long-term influence of tillage and nutrient management treatments practiced under rainfed pearl millet system on 19 soil quality indices has been statistically analyzed and it was observed that out of 19 soil quality parameters, five variables viz., pH, available P, available Fe, labile carbon and MWD were insignificant and hence were dropped from further PCA analysis. In the PCA of 14 variables, four PCs had eigen values >1 and explained 74.4% variance in the data set (Table 73). In PC1, three variables viz., EC, available N and DHA and in PC2, available N and exchangeable Mg were the highly weighted variables. The correlation analysis run between the variables individually under PC1 and PC2 showed that the correlation between the variables was significant but the variables were not well correlated ($r < 0.70$) (Table 74). Hence, all the variables under PC1 and PC2 were considered for inclusion under final MDS. In PC3 and PC4, the variables viz., BD and MBC were the sole variables qualified respectively. Hence, the indicators retained under each PC and qualified for final MDS included EC, available N, exchangeable Mg, available Mn, DHA, MBC and BD and were termed as the key indicators for rainfed pearl millet system in Aridisols of Hissar.

Table 73: Principal component analysis of soil quality parameters as influenced by different tillage and nutrient management treatments under rainfed pearl millet system in Aridisols of Hissar

	PC1	PC2	PC3	PC4
Total Eigen values	3.815	3.389	1.978	1.228
% of Variance	27.25	24.21	14.12	8.77
Cumulative %	27.25	51.46	65.59	74.36
Eigen Vectors				
EC	0.665	-0.407	0.349	-0.098
OC	0.476	-0.634	0.083	0.177
N	0.736	0.422	-0.071	-0.199
K	-0.517	-0.233	0.606	0.429
Ca	0.382	-0.678	-0.284	0.237
Mg	-0.212	0.787	-0.030	0.198
S	-0.757	-0.419	-0.127	0.043
Zn	0.608	0.644	-0.176	0.094
Cu	0.471	0.511	0.314	0.345
Mn	-0.234	0.748	0.454	0.026
B	0.542	-0.267	0.437	0.222
DHA	0.674	-0.145	0.377	-0.345
MBC	0.359	0.058	-0.479	0.739
BD	-0.222	-0.064	0.693	0.154

Table 74: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs			
PC1	EC	N	DHA
EC	1.00	0.343	0.557**
N	0.343	1.00	0.359
DHA	0.557*	0.359	1.00
Correlation sum	1.90	1.702	1.916
PC2	Mg	N	
Mg	1.00	0.652**	
N	0.652**	1.00	
Correlation sum	1.652	1.652	

*correlation is significant at P = 0.05 level
**correlation is significant at P = 0.01 level

4.2.18.3. Soil quality indices

Soil quality indices were computed using seven key soil quality indicators viz., EC, available N, exchangeable Mg, available Mn, DHA, MBC and BD. The soil quality indices varied from 1.50 to 1.74 across the tillage and nutrient management treatments practiced for rainfed pearl millet system (Table 75 & Fig 61). The soil quality indices, when reduced to a scale of one, termed as 'relative soil quality indices' (RSQI) varied between 0.83 and 0.96. From the data, it was observed that the practice of conventional tillage (CT) + two intercultures (IC) + 100% N (organic source/compost) and CT + two IC + 100% N (inorganic source) maintained the highest soil quality indices of 1.74 which is at par with other tillage and nutrient management practices. When averaged over the nutrient management treatments, practice of conventional tillage with two interculture operations performed better in maintaining significantly highest soil quality index of 1.74, while the practice of low tillage with two interculture operations or weedicide application + one interculture operation, both maintained the soil quality index of 1.60 (Fig 62). Among the nutrient management treatments, when averaged over tillage practices, application of 100% N through organic sources recorded significantly highest SQI of 1.69 which was at par with the other treatments. Irrespective of their statistical significance, the relative order of performance in influencing soil quality in terms of SQI was: T1: CT + Two IC + 100% N (organic source/compost) (1.74) > T3: CT + Two IC + 100% N (inorganic source) (1.74) > T4: LT + Two IC + 100% N (organic source/compost) (1.70) > T8: LT + Weedicide + One IC + 50% N (organic) + 50 % inorganic source) (1.68) > T2: CT + Two IC + 50% N (organic) + 50 % inorganic source) (1.64) > T7: LT + Weedicide + One IC + 100% N (organic source/compost) (1.63) > T5: LT + Two IC + 50% N (organic) + 50 % inorganic source) (1.59) > T6: LT + IC + 100% N (inorganic source) (1.50) > T9: LT + Weedicide + One IC + 100% N (inorganic source) (1.50). The average percent contribution of key indicators towards soil quality indices was: EC (15%), available N

(19%), exchangeable Mg (18%), available Mn (13%), dehydrogenase assay (19%), microbial biomass carbon (5%) and bulk density (11%) (Fig 63).

Table 75: Soil quality indices and relative soil quality indices of tillage and nutrient management treatments under pearl millet system in Aridisols of Hissar

SNo	Name of the treatments	SQI	RSQI
1	T1: CT + Two IC + 100% N (organic source/compost)	1.74	0.96
2	T2: CT + Two IC + 50% N (organic) + 50 % inorganic source)	1.64	0.91
3	T3: CT + Two IC + 100% N (inorganic source)	1.74	0.96
4	T4: LT + Two IC + 100% N (organic source/compost)	1.70	0.94
5	T5: LT + Two IC + 50% N (organic) + 50 % inorganic source)	1.59	0.88
6	T6: LT + IC + 100% N (inorganic source)	1.50	0.83
7	T7: LT + Weedicide + One IC + 100% N (organic source/compost)	1.63	0.90
8	T8: LT + Weedicide + One IC + 50% N (organic) + 50 % inorganic source)	1.68	0.93
9	T9: LT + Weedicide + One IC + 100% N (inorganic source)	1.50	0.83
	CD @ 0.05		
	Between two main treatment means	0.07	0.04
	Between two sub treatment means	0.06	0.03
	Between two sub treatment means at same main treatments	0.10	0.05
	Between two main treatment means at same or different sub treatments	0.09	0.05

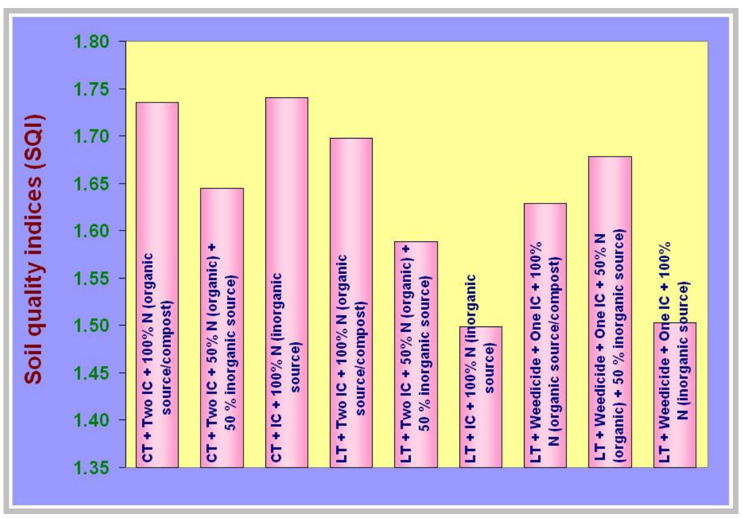


Fig 61: Soil quality indices of different tillage and nutrient management treatments practiced under rainfed pearl millet system in Aridisols of Hissar

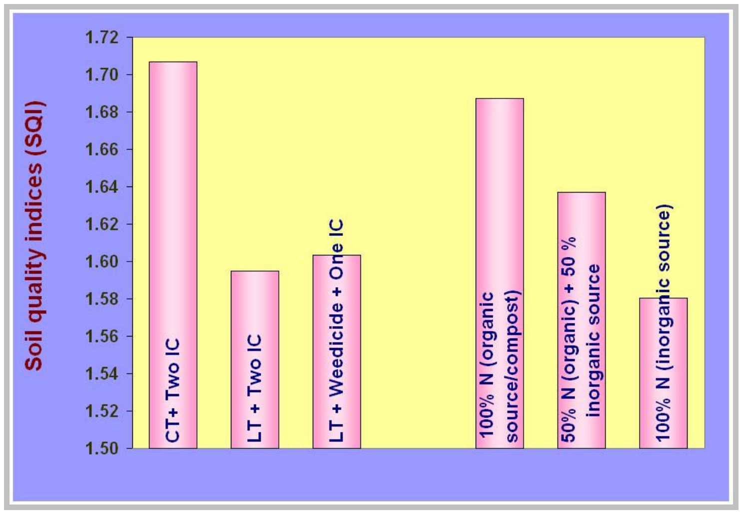


Fig 62: Average effects of different tillage and nutrient management treatments on soil quality indices practiced under rainfed pearl millet system in Aridisols of Hissar

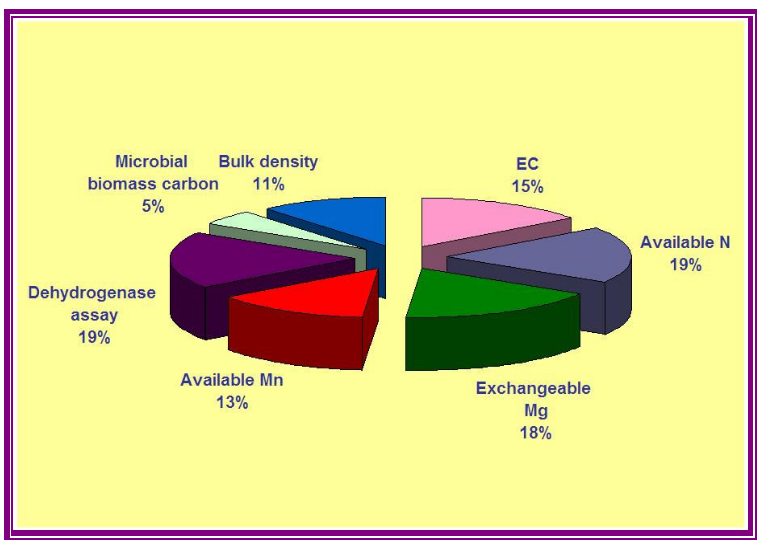


Fig 63: Percent contribution of key indicators towards soil quality indices under rainfed pearl millet system in Aridisols of Hissar

4.2.19. Experiment 4: Farmers Fields

Four cropping systems from the farmers fields of Hissar centre viz., i) pearl millet – fallow, ii) fallow – chickpea, iii) mung bean and iv) undisturbed systems were chosen to assess the performance of these systems in influencing or sustaining the soil quality. The data obtained on soil quality parameters under these situations is presented in Tables 76 to 78.

Soil pH in different cropping systems practiced in the farmer's fields ranged from 7.24 to 7.73 while the undisturbed field recorded a pH of 7.81 (Table 76). Electrical conductivity of soil in farmer's fields varied from 0.12 to 0.22 dS m^{-1} and was insignificant. Organic carbon was significantly highest under pearl millet – fallow system (2.54 g kg^{-1}) followed by mung bean system (2.43 g kg^{-1}) while the undisturbed site recorded slightly highest OC of 2.83 g kg^{-1}. The cropping systems did not show any significant difference in their available N content. However, it varied from 124.6 kg ha^{-1} under fallow- chickpea system to 138.7 kg ha^{-1} under mung bean system. Available P was almost similar in all the cropping systems of farmer's fields ranging from 21.9 to 23.4 kg ha^{-1}. Among the cropping systems, available K status was significantly highest under mung bean system (288.6 kg ha^{-1}) while the other two systems recorded available K upto 229 kg ha^{-1}. The undisturbed system showed available K status upto 359.6 kg ha^{-1} (Fig 64).

Table 76: Influence of different cropping systems on physico-chemical and chemical soil quality parameters under farmer's fields in Aridisols of Hissar

SNo	Cropping systems	pH	EC dS m^{-1}	OC (g kg^{-1})	N (kg ha^{-1})	P	K
1	Pearl millet - Fallow	7.24	0.12	2.54	128.8	21.9	229.6
2	Fallow - Chickpea	7.34	0.12	2.34	124.6	23.4	228.5
3	Mung bean	7.73	0.22	2.43	138.7	23.3	288.6
4	Undisturbed	7.81	0.17	2.83	153.0	16.8	359.6
	CD @ 0.05	0.25	NS	0.23	NS	4.27	81.2

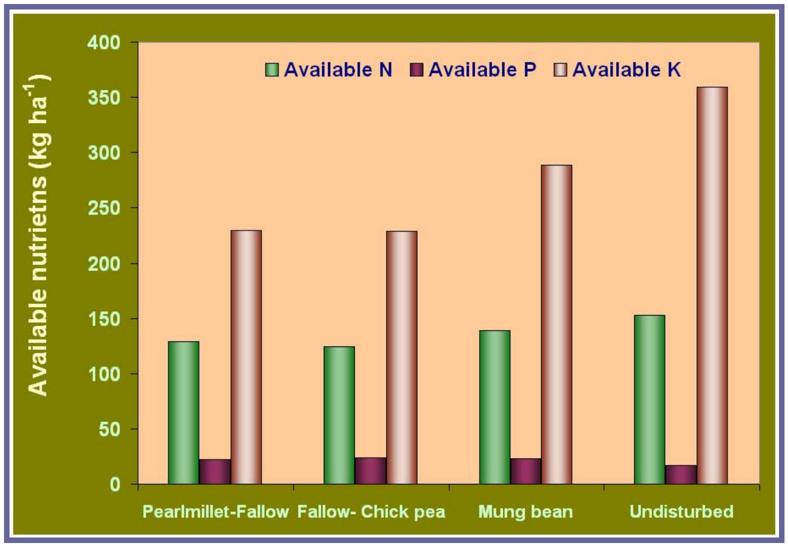


Fig 64: Influence of different cropping systems on chemical soil quality parameters (macronutrients) under farmer's fields in Aridisols of Hissar

Among the secondary nutrient parameters, available S ranging from 21.5 to 26.3 kg ha^{-1} was not significantly different under different cropping systems (Table 77 & Fig 65). Among the cropping systems, exchangeable Ca (2.75 cmol kg^{-1}) and exchangeable Mg (1.93 cmol kg^{-1}) were highest under mung bean system. Undisturbed sample recorded high exchangeable Ca to the extent of 3.12 cmol kg^{-1}. Among the micronutrients, the cropping systems significantly influenced available Fe, Cu and B but not available Zn and Mn. However, available Zn varied from 0.25 to 0.42 μg g^{-1} while available Mn ranged from 3.74 to 4.66 μg g^{-1} across the cropping systems. Pearl millet-fallow system recorded significantly highest available Fe of 5.11 μg g^{-1} while mung bean system recorded highest available B (1.61 μg g^{-1}) (Fig 66).

Table 77: Influence of different cropping systems on chemical soil quality parameters under farmer's fields in Aridisols of Hissar

SNo	Name of the treatments	Ca	Mg	S (kg ha^{-1})	Zn	Fe	Cu	Mn	B
		cmol kg^{-1}			μg g^{-1}				
1	Pearl millet- Fallow	1.65	1.06	21.5	0.30	5.11	0.14	4.42	0.38
2	Fallow – Chickpea	1.45	1.05	24.1	0.25	4.01	0.11	4.66	0.45
3	Mung bean	2.75	1.93	24.4	0.42	2.53	0.24	4.52	1.61
4	Undisturbed	3.12	1.47	26.3	0.34	3.14	0.37	3.74	1.26
	CD @ 0.05	0.51	0.54	NS	NS	1.28	0.12	NS	0.26

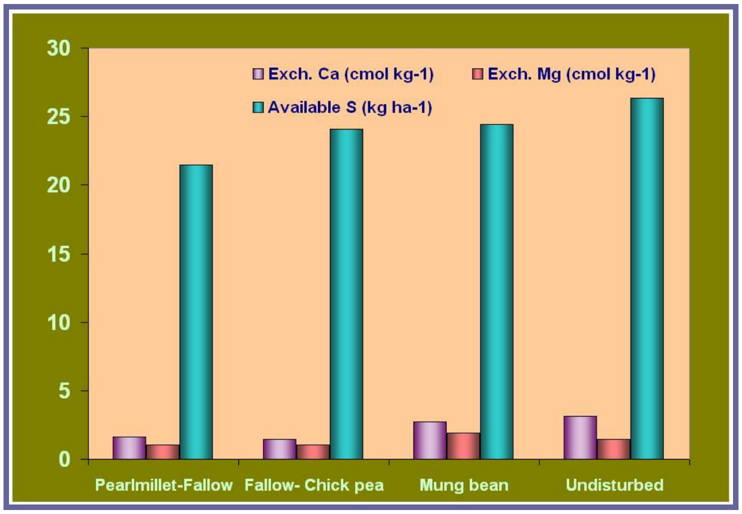


Fig 65: Influence of different cropping systems on chemical soil quality parameters (secondary nutrients) under farmer's fields in Aridisols of Hissar

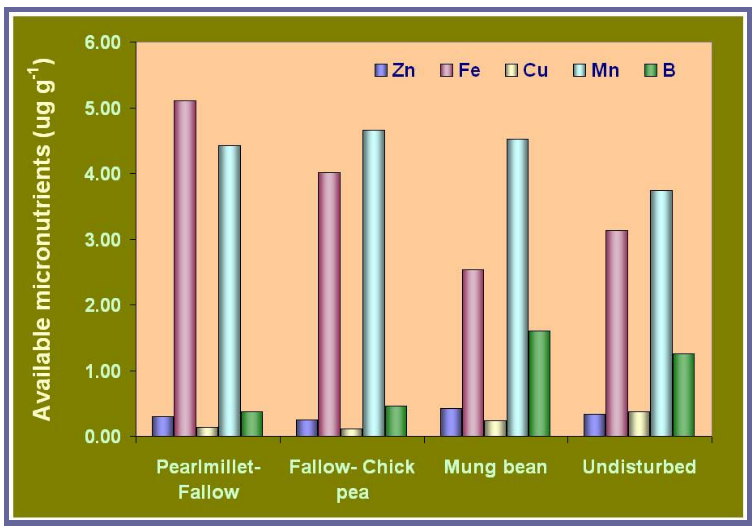


Fig 66: Influence of different cropping systems on chemical soil quality parameters (micronutrients) under farmer's fields in Aridisols of Hissar

Among the biological soil quality parameters, the cropping systems showed a significant influence on labile carbon in soils but not dehydrogenase activity as well as microbial biomass carbon (Table 78 & Fig 67). Though significantly highest labile carbon was recorded under undisturbed sample, among the cropping systems, it was the mung bean system, which recorded significantly highest labile carbon, which was to the extent of 230.7 µg g^{-1} of soil. Inspite of the insignificant influence of cropping systems, DHA varied from 1.23 to 1.39 µg TPF $hr^{-1}g^{-1}$ while MBC ranged from 102.2 to 129.4 µg g^{-1} of soil. Among the physical soil quality indicators, bulk density under both pearl millet-fallow system as well as fallow-chickpea system was 1.37 Mg m^{-3}, while the mung bean system it was 1.42 Mg m^{-3}. It was observed that almost all the cropping systems in farmer's fields recorded a mean weight diameter of 0.17 mm except the undisturbed, which recorded a mean weight diameter of 0.30 mm (Fig 68).

Table 78: Influence of different cropping systems on biological and physical soil quality parameters under farmer's fields in Aridisols of Hissar

SNo	Name of the treatments	DHA (µg TPF $hr^{-1}g^{-1}$)	MBC (µg g^{-1} of soil)	LC (µg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	Pearl millet- Fallow	1.39	102.2	161.7	1.37	0.17
2	Fallow – Chickpea	1.23	127.1	143.8	1.37	0.16
3	Mung bean	1.30	129.4	230.7	1.42	0.17
4	Undisturbed	2.25	126.0	250.5	1.72	0.30
	CD @ 0.05	NS	NS	66.1	0.05	0.03

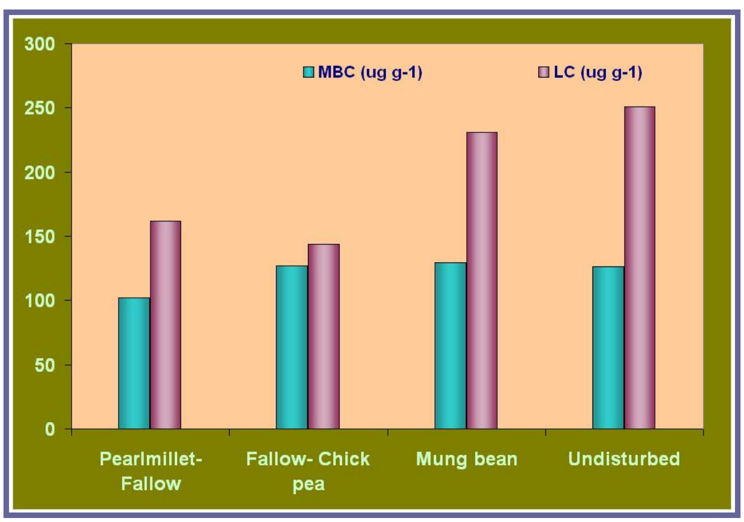


Fig 67: Influence of different cropping systems on biological soil quality parameters under farmer's fields in Aridisols of Hissar

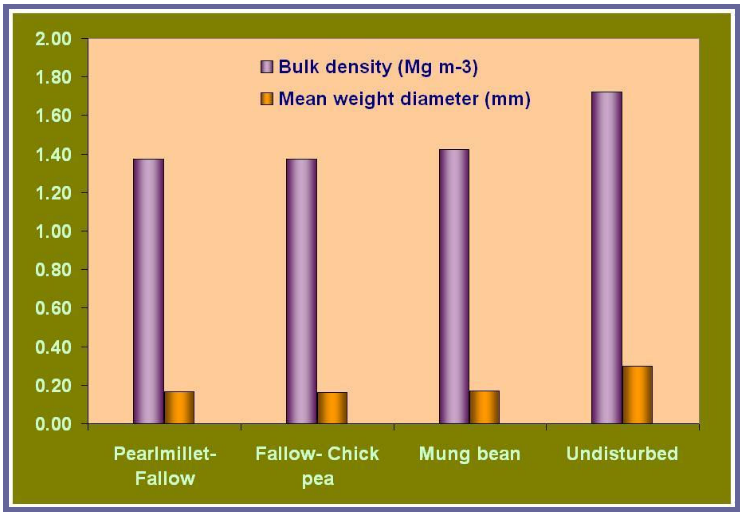


Fig 68: Influence of different cropping systems on physical soil quality parameters under farmer's fields in Aridisols of Hissar

4.2.19.1. Key indicators and soil quality assessment

4.2.19.2. Results of principal component analysis

Data pertaining to the influence of various cropping systems practiced under farmer's fields on 19 soil quality indices has been statistically analyzed and it was observed that out of 19 soil quality parameters, 7 variables viz., EC, available N, S, Zn, Mn, dehydrogenase assay, and microbial biomass carbon were insignificant and hence were dropped from further PCA analysis. In the PCA of 12 variables, two PCs had eigen values >1 and explained 84.3 % variance in the data set (Table 79). In PC1, six variables viz., pH, available K, exchangeable Ca, available Cu, labile carbon and bulk density were the highly weighted variables while in PC2 only single variable ie exchangeable Mg was highly weighted. The correlation analysis run between the variables individually under PC1 showed that the correlations were significant and the variables were also well correlated (>0.70) (Table 80). But considering their importance in these soils, all the highly weighted variables under PC1 were retained to be included under MDS. Hence, the final MDS included pH, available K, exchangeable Ca & Mg, available Cu, labile carbon and bulk density and were termed the key indicators for different cropping systems practiced in farmer's fields of Hissar.

Table 79: Principal component analysis of soil quality parameters as influenced by different cropping systems under farmers fields at Hissar

	PC1	PC2
Total Eigen values	7.749	2.364
% of Variance	64.58	19.70
Cumulative %	64.58	84.28
Eigen Vectors		
pH	0.864	0.297
OC	0.712	-0.535
P	-0.635	0.583
K	0.908	-0.117
Ca	0.950	0.133
Mg	0.494	0.742
Fe	-0.666	-0.528
Cu	0.902	-0.106
B	0.772	0.610
LC	0.880	0.142
BD	0.883	-0.361
MWD	0.844	-0.504

Table 80: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs	pH	K	Ca	Cu	LC	BD
pH	1.00	0.669*	0.818**	0.712**	0.723**	0.693*
K	0.669*	1.00	0.886**	0.880**	0.871**	0.786**
Ca	0.818**	0.886**	1.00	0.866**	0.925**	0.768**
Cu	0.712**	0.880**	0.866**	1.00	0.883**	0.856**
LC	0.723**	0.871**	0.925**	0.883**	1.00	0.688*
BD	0.693*	0.786**	0.768**	0.856**	0.688*	1.00
Correlation sum	4.615	5.092	5.263	5.197	5.09	4.791

*correlation is significant at P = 0.05 level
**correlation is significant at P = 0.01 level

4.2.19.3. Soil quality indices

Soil quality indices were computed using seven key soil quality indicators viz., pH, available K, exchangeable Ca & Mg, available Cu, labile carbon and bulk density. The soil quality indices varied from 2.87 to 4.13 across the farmer's fields (Table 81). The soil quality indices, when reduced to a scale of one, termed as 'relative soil quality indices' (RSQI) varied between 0.65 and 0.93 (Fig 69). From the data, it was observed that undisturbed system had the highest SQI of 4.13. But among the cropping systems, mung bean system had the highest SQI of 3.82. Irrespective of their statistical significance, the relative order of performance of the cropping systems in influencing soil quality in terms of SQI was: Undisturbed (4.13) > Mung bean (3.82) > Pearl millet- Fallow (3.00) > Fallow – Chickpea (2.87). The average percent contribution of key indicators towards soil quality indices was: pH (22%), available K (16%), exchangeable Ca (14%), exchangeable Mg (4%), available Cu (9%), labile carbon (15%) and bulk density (20%) (Fig 70).

Table 81: Soil quality indices and relative soil quality indices of the management treatments

SNo	Name of the treatments	SQI	RSQI
1	Pearl millet- Fallow	3.00	0.68
2	Fallow – Chickpea	2.87	0.65
3	Mung bean	3.82	0.86
4	Undisturbed	4.13	0.93
	CD @ 0.05	0.48	0.11

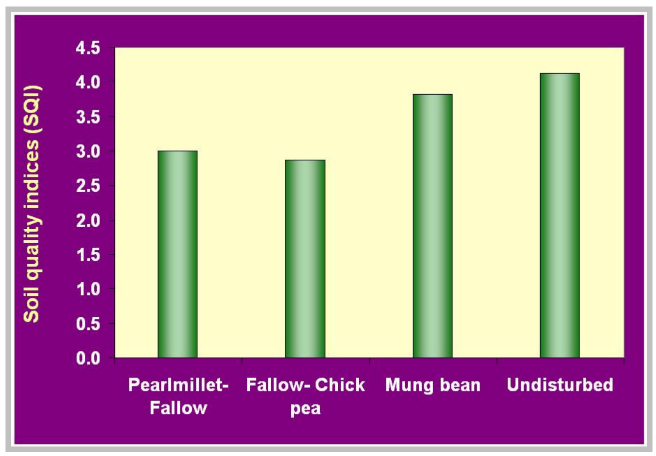


Fig 69: Soil quality indices of different cropping systems practiced under farmer's fields in Aridisols of Hissar

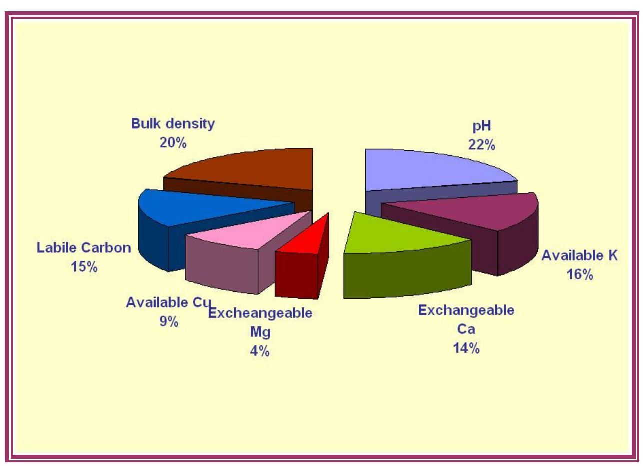


Fig 70: Percent contribution of key indicators towards soil quality indices under different cropping systems of farmer's fields in Aridisols of Hissar

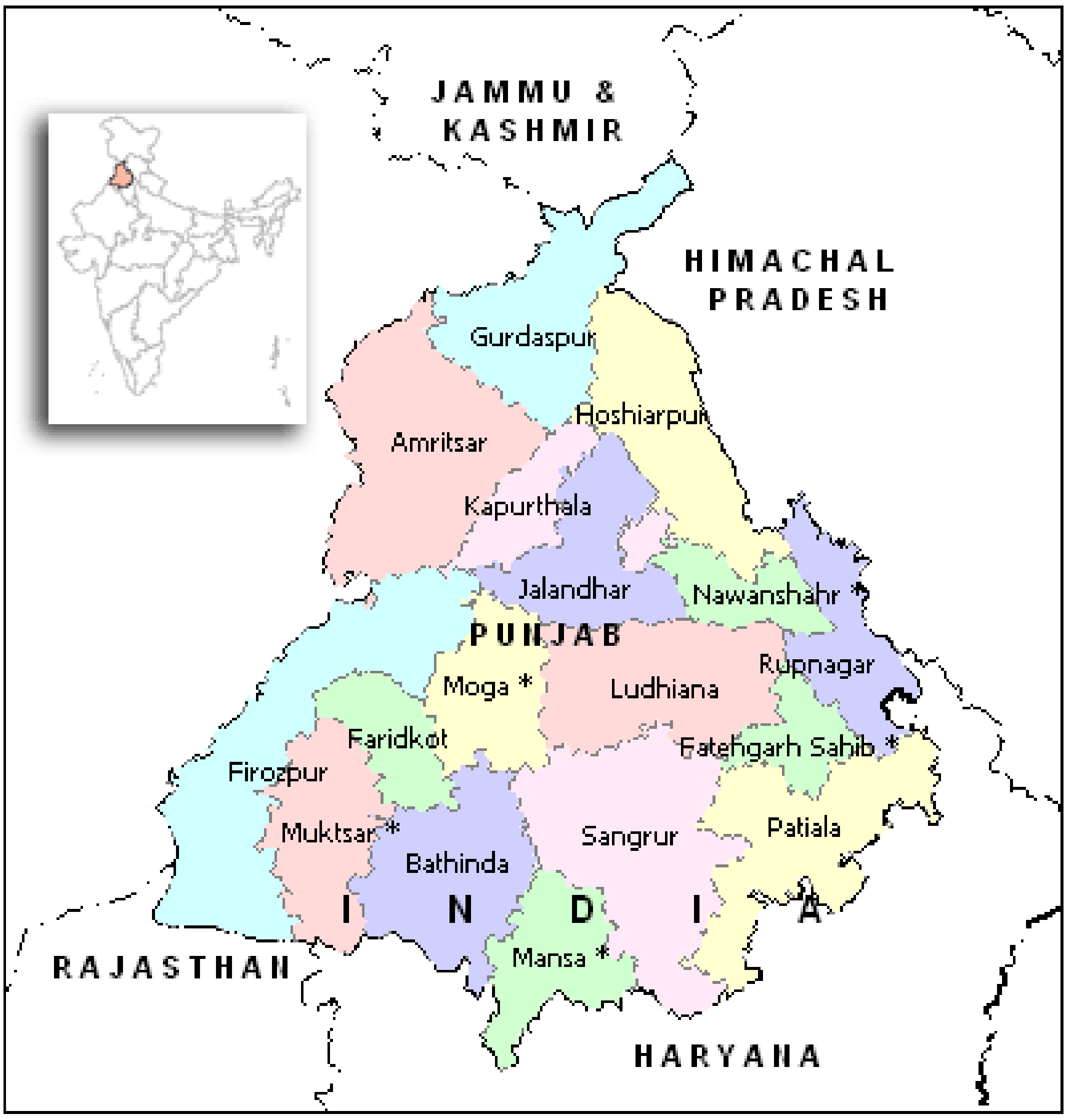
Table 82: Summary of soil quality indices and relative soil quality indices as influenced by different soil nutrient management practices under different trials practiced in Aridisols of Hissar.

Sno		SQI	RSQI
Experiment 1: Integrated nutrient supply for rainfed semiarid tropics			
1	T1: Control	1.11	0.70
2	T2: 100% N (inorganic)	1.45	0.92
3	T3: 25 kg N (compost)	1.52	0.97
4	T4: 15 kg N (GLM) + 20 kg N (inorganic)	1.46	0.93
5	T5: 15 kg N (compost) + 10 kg N (GLM)	1.47	0.94
6	T6: 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer	1.49	0.95
Experiment 2: Organic farming studies on rainfed mustard			
1	T1: Control	0.71	0.65
2	T2: FYM (4 t ha^{-1})	1.04	0.95
3	T3: Vermiculture (4 tha^{-1})	0.95	0.88
4	T4: Diancha Green manure (40 DAS)	0.89	0.82
5	T5: Cowpea green manure (40 DAS)	1.00	0.92
Experiment 3: Tillage and nutrient management strategies for resource conservation and improving soil quality and productivity of rainfed pearl millet			
1	T1: CT + Two IC + 100% N (organic source/compost)	1.74	0.96
2	T2: CT + Two IC + 50% N (organic) + 50 % inorganic source)	1.64	0.91
3	T3: CT + Two IC + 100% N (inorganic source)	1.74	0.96
4	T4: LT + Two IC + 100% N (organic source/compost)	1.70	0.94
5	T5: LT + Two IC + 50% N (organic) + 50 % inorganic source)	1.59	0.88
6	T6: LT + IC + 100% N (inorganic source)	1.50	0.83
7	T7: LT + Weedicide + One IC + 100% N (organic source/compost)	1.63	0.90
8	T8: LT + Weedicide + One IC + 50% N (organic) + 50 % inorganic source)	1.68	0.93
9	T9: LT + Weedicide + One IC + 100% N (inorganic source)	1.50	0.83
Experiment 4: Cropping systems at Farmers fields			
1	Pearl millet- Fallow	3.00	0.68
2	Fallow – Chickpea	2.87	0.65
3	Mung bean	3.82	0.86
4	Undisturbed	4.13	0.93

Table 83: Summary of key soil quality indicators, soil quality indices and the best soil nutrient management practices identified under different cropping systems in Aridisols of Hissar

Sno	Key soil quality indicators and their % contribution	SQI	RSQI	Best management practices with higher SQI
Experiment 1: Integrated nutrient supply for rainfed semiarid tropics				
	• Available N (35%) • Available Zn (35%) • Available Cu (10%) • pH (10%) • Available K (5%) • Dehydrogenase assay (5%)			1. Application of 25 kg N (compost) (1.52) 2. Application of 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer (1.49) 3. Application of 15 kg N (compost) + 10 kg N (GLM) (1.47)
Experiment 2: Organic farming studies on rainfed mustard				
	• Available Zn (63%) • Exchangeable Mg (13%) • Available Fe (11%) • Available P (7%)			1. Application of FYM (4 t ha^{-1}) (1.04) 2. Application of Cowpea green manure (40 DAS) (1.00) 3. Application of Vermiculture (4 tha^{-1}) (0.95)
Experiment 3: Tillage and nutrient management strategies for resource conservation and improving soil quality and productivity of rainfed pearl millet				
	• EC (15%) • Available N (19%) • Exchangeable Mg (18%) • Available Mn (13%) • Dehydrogenase assay (19%) • Microbial biomass carbon (5%) • Bulk density (11%)			1. CT + Two IC + 100% N (organic source/compost) (1.74) 2. CT + Two IC + 100% N (inorganic source) (1.74) 3. LT + Two IC + 100% N (organic source/compost) (1.70)
Experiment 4: Cropping systems at Farmers fields				
	• pH (22%) • Available K (16%) • Exchangeable Ca (14%) • Exchangeable Mg (4%) • Available Cu (9%) • Labile carbon (15%) • Bulk density (20%)			1. Undisturbed (4.13) 2. Mung bean (3.82) 3. Pearl millet- Fallow (3.00) 4. Fallow – Chickpea (2.87)

Ballowal-Saunkri Centre
(Hoshiarpur)
Maize based production system



4.2.20. Effect of predominant soil and nutrient management practices on soil quality indicators (attributes) and soil quality indices at Ballowal Saunkhri, Hoshiarpur centre of AICRPDA

Location description, climate and soil characteristics

This centre represents the Kandi area of Punjab, and is located along the northeastern border of the state. Physiographically, this region is sub-montane undulating region and comprises of about 10 % of total area of the state. Altitude wise, this region falls between 300 to 550 m above mean sea level. This region is divided by many streams, which result in flash floods during monsoon season. Underground water is inadequate and inaccessible because of poor water bearing aquifers. Climatically, this region represents sub- humid type of climate with annual rainfall of about 1000 mm. The major portion of these rains (about 80 %) is received during late June to mid September. Mean monthly rainfall is the highest in July and lowest in April. Rainfall is relatively more erratic during sowing time of *kharif* crops and is erratic as well as low during sowing of *rabi* crops. Runoff varies from 20-45 percent during monsoon period. Generally, summers are hot and winters are very cool. The maximum temperature is generally recorded in the month of May-June (upto 41^{o}C) and the minimum in the month of January (up to 3^{o}C).

Predominantly, land of this region represents three distinct physiographic units: (1) hilly (2) gently to moderately sloppy agricultural land and (3) stream affected marginal land. In general, soils are neutral in reaction and low in organic matter content. Fertility wise, these soils are deficient in nitrogen, low in available phosphorus and medium in available potassium. These soils are light in texture with loamy sand and sandy loam. North western part of the region has relatively medium to heavy texture soil. The important crops grown in the region are maize, pearl millet, green gram, black gram, ground nut, wheat, barley, lentil, mustard, taramira and chick pea.

In order to study the effect of predominant soil and nutrient management practices on soil quality indicators, and the soil quality indices, the following experiments were chosen at Ballowal Saunkhri, Hoshiarpur centre.

- Experiment 1: Integrated nutrient management practices in maize/black gram – wheat/lentil cropping systems under rainfed semi-arid tropics

- Experiment 2: Effect of tillage and sources of nitrogen on the crop productivity in maize-wheat cropping sequence under dryland conditions
- Experiment 3: Farmer's fields

4.2.21. Experiment 1: Integrated nutrient management practices in maize/black gram – wheat/lentil cropping systems under rainfed semi-arid tropics

To study the long-term effect of organic and inorganic sources of nutrients on the productivity of crops and soil quality in cereal–pulse (maize / moong – wheat /lentil) based cropping sequence, the present long-term experiment was started in kharif 2000 with nine treatments comprising of different combinations of organic and inorganic sources of nitrogen. The experiment was laid out in a randomized block design with three replications. The nine treatments were as follows: T1: No fertilizer, T2: 100 % RDN (80 kg N ha^{-1}), T3: 50% RDN (40 kg N ha^{-1}), T4: 25 kg N (compost), T5: 15 kg N (compost) + 10 kg N ha^{-1} (inorganic), T6: 15 kg N (compost) + 20 kg N ha^{-1} (inorganic), T7: 15 kg N (green leaf) + 10 kg N ha^{-1} (inorganic), T8: 15 kg N (green leaf) + 20 kg N ha^{-1} (inorganic) and T9: 15 kg N (compost) + 10 kg N ha^{-1} (green leaf).

Soil quality assessment studies were undertaken in this experiment after five years of experimentation. In order to assess the impact of this long-term soil-nutrient management on soil quality, soils were analyzed for 19 physical, chemical and biological indicators and relative soil quality indices were computed. The data on soil quality indicators have been presented in Tables 84 to 86.

Soil reaction of the experimental plot was not significantly influenced by the management treatments. However, the soils were found to be slightly alkaline in reaction with the pH varying from 7.38 to 7.83 across the treatments. Similar was the case with electrical conductivity, which ranged from 0.19 to 0.22 dS m^{-1} across the treatments. Soil organic carbon was significantly influenced by the management treatments. Among all the treatments, application of 100% RDN (80 kg N ha^{-1}), 15 kg N (compost) + 20 kg N ha^{-1} (inorganic), 25 kg N (compost) and 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) were almost at par and recorded the highest organic carbon contents of 5.57, 5.32, 5.27 and 5.26 g kg^{-1} respectively, while the lowest amount was recorded in control (4.3 g kg^{-1}).

Available nitrogen content in the soil was significantly influenced by the management treatments and varied from 134.5 to 187.3 kg ha^{-1}. Two treatments viz., application of 100% RDN and 25 kg

N (compost) recorded significantly highest nitrogen contents of 187.3 and 183.1 kg ha^{-1} respectively and were found almost at par with each other followed by 50% RDN (166.1 kg ha^{-1}). However, control plot (134.5 kg ha^{-1}) recorded the lowest. Available P and K were also found to be significantly influenced by the management treatments and varied between 18.53 to 32.25 kg ha^{-1} and 148.97 to 197.36 kg ha^{-1} respectively. Application of 25 kg N (compost) recorded significantly highest available P content of 32.25 kg ha^{-1} which was at par with 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) (29.87 kg ha^{-1}) while, the lowest amount was observed under control (18.53 kg ha^{-1}). Significantly highest available potassium was recorded under 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) (197.36 kg ha^{-1}) followed by 25 kg N (compost) (181.47 kg ha^{-1}) and the lowest in 100% RDN (148.97 kg ha^{-1}) (Fig 71).

Exchangeable calcium in these soils varied between 4.51 to 6.95 cmol kg^{-1} and was significantly influenced by the management practices. Almost six treatments (T3 to T9) were found to be significantly at par with each other with regard to the exchangeable calcium content, the range being 4.51 to 6.95 cmol kg^{-1}. Exchangeable magnesium was not significantly influenced by the management treatments. However, it varied from 0.57 to 0.84 cmol kg^{-1} across the treatments. Management treatments significantly influenced available sulphur content in the soils and it varied from 9.35 to 18.26 kg ha^{-1} across the treatments. Application of 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) recorded the highest amount (18.26 kg ha^{-1}) of available sulphur which was followed by 15 kg N (compost) + 10 kg N ha^{-1} (inorganic) (15.98 kg ha^{-1}) (Fig 72).

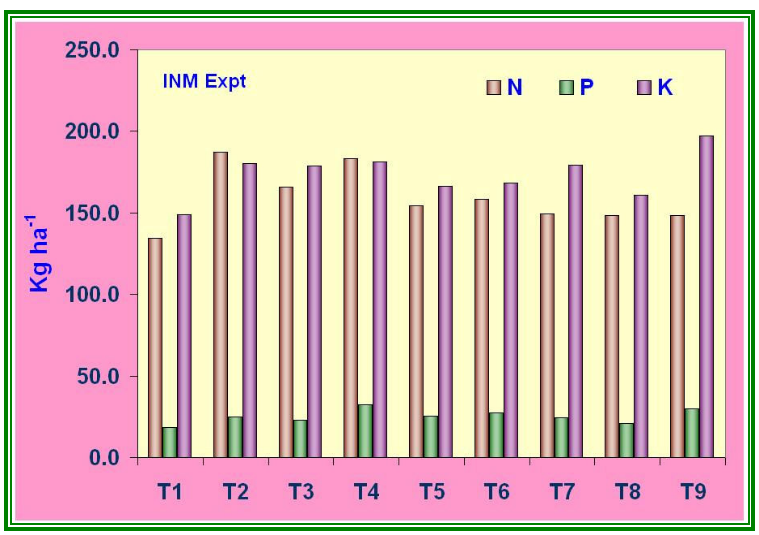


Fig 71: Effect of different soil-nutrient management (INM) treatments on macronutrients under Maize-Wheat based cropping sequence in Inceptisols of Ballowal Saunkhri

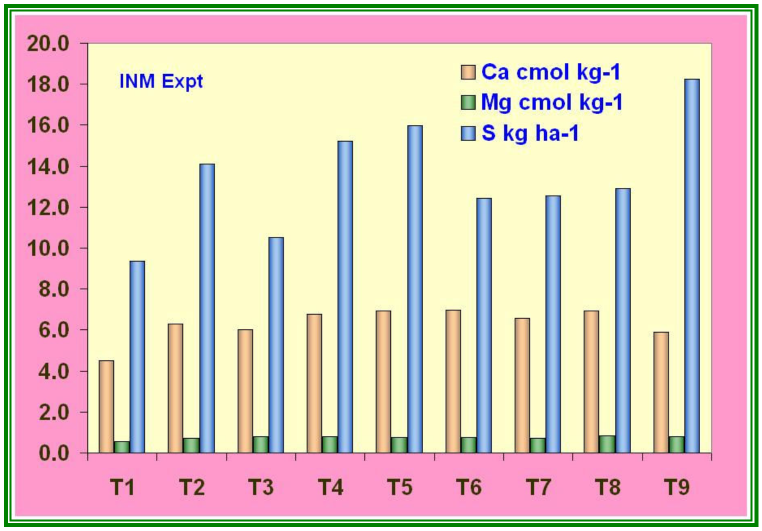


Fig 72: Effect of different soil-nutrient management (INM) treatments on secondary nutrients under Maize-Wheat based cropping sequence in Inceptisols of Ballowal Saunkhri

Among the micronutrients, available Zn, Fe and B were significantly influenced by the management treatments and varied between 0.51 to 0.87, 5.03 to 7.58 and 0.97 to 1.27 µg g^{-1} of soil respectively (Fig 73). Available Zn and Fe were found to be significantly highest under 25 kg N (compost) treatments, while available B was found to be highest under 15 kg N (compost) + 20 kg N ha^{-1} (inorganic) (1.27 µg g^{-1} of soil) followed by 15 kg N (green leaf) + 10 kg N ha^{-1} (inorganic) (1.18 µg g^{-1} of soil) which was at par with that of 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) (1.18 µg g^{-1} of soil). The management treatments did not show any significant influence on the available Cu and Mn contents, however, their contents varied from 0.49 to 0.62 and 10.17 to 12.48 µg g^{-1} of soil respectively.

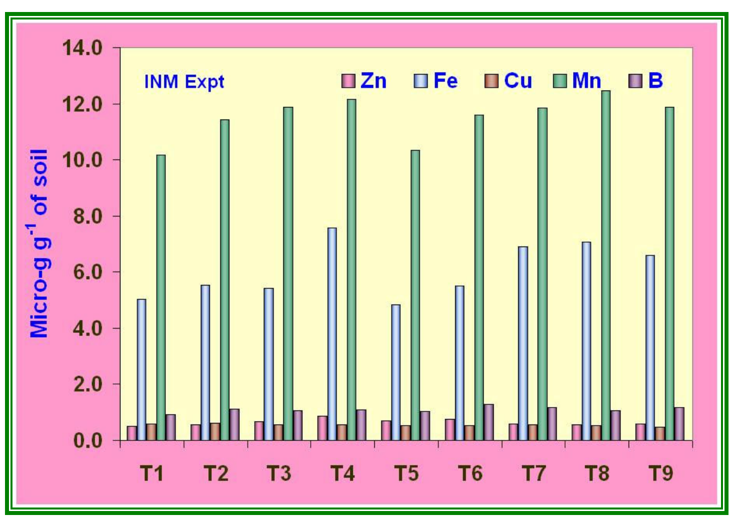


Fig 73: Effect of different soil-nutrient management (INM) treatments on micronutrients contents under maize-wheat based cropping sequence in Inceptisols of Ballowal Saunkhri

Among the biological indicators, dehydrogenase assay in the soils varied from 2.48 to 3.01 μg TPF $hr^{-1}g^{-1}$ and was not significantly influenced by the management treatments. However, the management treatments had significant influence on microbial biomass carbon and labile carbon which ranged from 112.99 to 166.79 and 329.12 to 361.31 μg g^{-1} of soil respectively (Fig 74). Among all the treatments, 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) recorded the highest microbial biomass carbon (166.79 μg g^{-1} of soil) and labile carbon 361.31 μg g^{-1} of soil) which were at par with those of 15 kg N (green leaf) + 10 kg N ha^{-1} (inorganic). The unamended control showed relatively lower values of MBC and labile carbon. The soil physical quality indicators viz., bulk density and mean weight diameter were not significantly influenced by the management treatments. However, bulk density in these soils ranged from 1.50 to 1.58 Mg m^{-3} while mean weight diameter of soil aggregates varied form 0.22 to 0.31 mm (Fig 75).

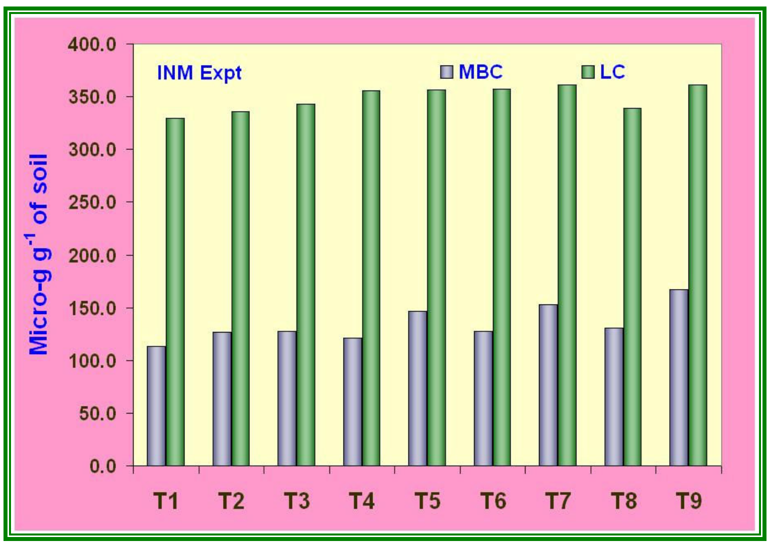


Fig 74: Effect of different soil-nutrient management (INM) treatments on biological soil quality parameters under maize-wheat based cropping sequence in Inceptisols of Ballowal Saunkhri

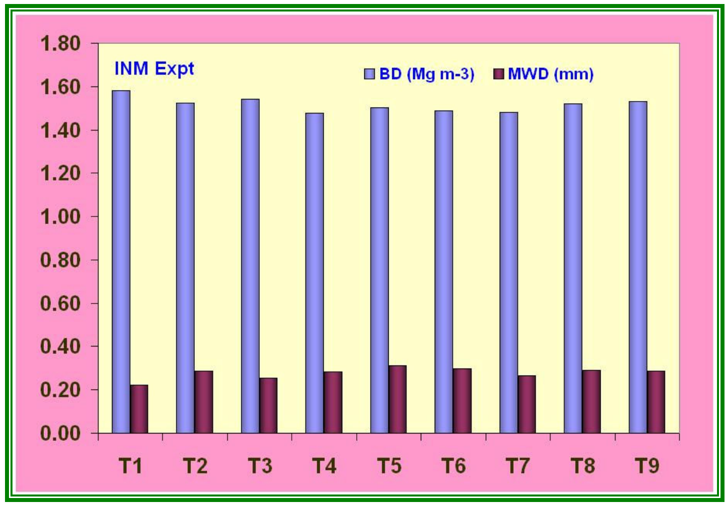


Fig 75: Effect of different soil-nutrient management (INM) treatments on physical soil quality parameters under maize-wheat based cropping sequence in Inceptisols of Ballowal Saunkhri

Table 84: Effect of different soil-nutrient management (INM) treatments on soil chemical characteristics under Maize-Wheat based cropping sequence in Inceptisols of Ballowal Saunkhri

Sno	Treatments	pH	EC ($dS\ m^{-1}$)	OC ($g\ kg^{-1}$)	N ($kg\ ha^{-1}$)	P ($kg\ ha^{-1}$)	K ($kg\ ha^{-1}$)
1	T1: No Fertilizer	7.38	0.22	4.27	134.5	18.5	149.0
2	T2: 100% RDN (80 kg N ha^{-1})	7.59	0.20	5.57	187.3	25.1	180.0
3	T3: 50% RDN (80 kg N ha^{-1})	7.81	0.20	5.13	166.1	23.2	178.7
4	T4: 25 kg N (compost)	7.57	0.19	5.27	183.1	32.3	181.5
5	T5: 15 kg N (compost) + 10 kg N ha^{-1} (inorganic)	7.80	0.21	4.80	154.6	25.4	166.3
6	T6: 15 kg N (compost) + 20 kg N ha^{-1} (inorganic)	7.55	0.22	5.32	158.6	27.3	168.2
7	T7: 15 kg N (green leaf) + 10 kg N ha^{-1} (inorganic)	7.50	0.21	4.53	149.6	24.3	179.2
8	T8: 15 kg N (green leaf) + 20 kg N ha^{-1} (inorganic)	7.67	0.20	4.80	148.4	20.9	160.9
9	T9: 15 kg N (compost) + 10 kg N ha^{-1} (green leaf)	7.83	0.19	5.23	148.4	29.9	197.4
	CD @ 0.05	NS	NS	0.60	18.6	3.60	13.6

Table 85: Effect of different soil-nutrient management (INM) treatments on soil micronutrients under Maize-Wheat based cropping sequence in Inceptisols of Ballowal Saunkhri.

Sno	Treatments	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	S (kg ha^{-1})	Zn	Fe	Cu	Mn	B
					$\mu g\ g^{-1}$				
1	T1: No Fertilizer	4.51	0.57	9.35	0.51	5.03	0.58	1.02	0.97
2	T2: 100% RDN (80 kg N ha^{-1})	6.31	0.74	14.1	0.55	5.53	0.62	11.4	1.11
3	T3: 50% RDN (80 kg N ha^{-1})	6.01	0.78	10.5	0.67	5.43	0.56	11.9	1.06
4	T4: 25 kg N (compost)	6.76	0.79	15.2	0.87	7.58	0.56	12.2	1.08
5	T5: 15 kg N (compost) + 10 kg N ha^{-1} (inorganic)	6.92	0.74	16.0	0.71	4.83	0.52	10.3	1.04
6	T6: 15 kg N (compost) + 20 kg N ha^{-1} (inorganic)	6.95	0.75	12.4	0.75	5.50	0.54	11.6	1.27
7	T7: 15 kg N (green leaf) + 10 kg N ha^{-1} (inorganic)	6.59	0.73	12.6	0.58	6.89	0.57	11.8	1.18
8	T8: 15 kg N (green leaf) + 20 kg N ha^{-1} (inorganic)	6.92	0.84	12.9	0.56	7.08	0.53	12.5	1.06
9	T9: 15 kg N (compost) + 10 kg N ha^{-1} (green leaf)	5.91	0.81	18.3	0.59	6.60	0.49	11.9	1.18
	CD @ 0.05	0.96	NS	2.97	0.15	1.61	NS	NS	0.15

Table 86: Effect of different soil- nutrient management (INM) treatments on soil biological and physical parameters under Maize-Wheat based cropping sequence in Inceptisols of Ballowal Saunkhri.

Sno	Treatments	DHA (μg TPF $hr^{-1} g^{-1}$)	MBC (μg g^{-1} of soil)	LC (μg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	T1: No Fertilizer	2.48	113.0	329.1	1.58	0.22
2	T2: 100% RDN (80 kg N ha^{-1})	2.85	126.6	335.5	1.52	0.29
3	T3: 50% RDN (80 kg N ha^{-1})	2.91	127.9	342.7	1.54	0.26
4	T4: 25 kg N (compost)	2.81	120.9	355.7	1.48	0.28
5	T5: 15 kg N (compost) + 10 kg N ha^{-1} (inorganic)	2.48	146.4	356.4	1.50	0.31
6	T6: 15 kg N (compost) + 20 kg N ha^{-1} (inorganic)	3.01	127.2	357.1	1.49	0.30
7	T7: 15 kg N (green leaf) + 10 kg N ha^{-1} (inorganic)	2.84	152.7	361.0	1.48	0.27
8	T8: 15 kg N (green leaf) + 20 kg N ha^{-1} (inorganic)	2.63	130.5	338.9	1.52	0.29
9	T9: 15 kg N (compost) + 10 kg N ha^{-1} (green leaf)	2.79	166.8	361.3	1.53	0.29
	CD @ 0.05	NS	14.5	21.6	NS	NS

4.2.21.1. Key indicators and soil quality assessment

4.2.21.2. Results of principal component analysis

Data pertaining to the influence of different soil- nutrient management (INM) treatments practiced under maize-wheat based cropping system on 19 soil quality indices has been statistically analyzed and it was observed that out of 19 soil quality parameters, 8 variables viz., pH, EC, exchangeable Mg, available Cu, Mn, dehydrogenase assay, bulk density and mean weight diameter were insignificant and hence were dropped from further PCA analysis. In the PCA of 11 variables, three PCs had eigen values >1 and explained 67.2 % variance in the data set (Table 87). In PC1 as well as in PC2 two variables each were qualified as highly weighted variables while in PC3, only single variable has been qualified. In PC1, the variables qualified were available P and K which had a correlation value of 0.610* (Table 88) which was < 0.70 and hence both were retained for the final MDS. Even in PC2, the two highly weighted variables viz, available N and MBC had no significant correlation and hence were retained for the final MDS. Hence, the final MDS included all the highly weighted variables viz., available N, available P, available K, exchangeable Ca and microbial biomass carbon and were termed the key indicators for different soil- nutrient management (INM) treatments under Maize-Wheat based cropping sequence in Inceptisols of Ballowal Saunkhri.

Table 87: Principal component analysis of soil quality parameters as influenced by different soil-nutrient management (INM) treatments under Maize-Wheat based cropping sequence in Inceptisols of Ballowal Saunkhri.

	PC1	PC2	PC3
Total Eigen values	4.459	1.789	1.149
% of Variance	40.534	16.260	10.446
Cumulative %	40.534	10.446	67.240
Eigen Vectors			
OC	0.621	0.383	-0.505
N	0.451	**0.718**	-0.178
P	**0.840**	0.179	0.016
K	**0.815**	-0.170	-0.386
Ca	0.478	0.229	**0.665**
S	0.773	-0.211	-0.101
Zn	0.561	0.453	0.343
Fe	0.453	-0.036	0.142
B	0.670	-0.180	0.007
MBC	0.517	**-0.776**	-0.067
LC	0.661	-0.356	0.345

Table 88: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs	P	K
PC1		
P	1.00	0.610**
K	0.610**	1.00
Correlation sum		
PC2	N	MBC
N	1.00	-0.236
MBC	-0.236	1.00
Correlation sum		

**correlation is significant at P = 0.01 level

4.2.21.3. Soil quality indices

Soil quality indices were computed using five key soil quality indicators viz., available N, available P, available K, exchangeable Ca and microbial biomass carbon. The soil quality indices varied from 1.16 to 1.61 across the treatments (Table 89). The soil quality indices, when reduced to a scale of one, termed as 'relative soil quality indices' (RSQI) varied between 0.70 to 0.98 (Fig 76). From the data, it was observed that application of 25 kg N (compost) (1.61) as well as application of 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) both recorded the highest SQI of 1.61. Irrespective of their statistical significance, the relative order of performance of the nutrient management treatments in influencing soil quality in terms of SQI was: T4: 25 kg N (compost) (1.61) = T9: 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) (1.61) > T2: 100% RDN (80 kg N ha^{-1}) (1.48) > T6: 15 kg N (compost) + 20 kg N ha^{-1} (inorganic) (1.47) > T7: 15 kg N (green leaf) + 10 kg N ha^{-1} (inorganic) (1.46) > T5: 15 kg N (compost) + 10 kg N ha^{-1} (inorganic) (1.45) > T3: 50% RDN (80 kg N ha^{-1}) (1.41) > T8: 15 kg N (green leaf) + 20 kg N ha^{-1} (inorganic) (1.32) > T1: No Fertilizer (1.16). The average percent contribution of key indicators towards soil quality indices was: available N (13%), available P (32%), available K (34%), exchangeable Ca (9%) and microbial biomass carbon (12%) (Fig 77).

Table 89: Soil quality indices and relative soil quality indices as influenced by different soil-nutrient management treatments in maize-wheat based cropping sequence at Ballowal Saunkhri

Sno	Treatments	SQI	RSQI
1	T1: No Fertilizer	1.16	0.70
2	T2: 100% RDN (80 kg N ha^{-1})	1.48	0.90
3	T3: 50% RDN (80 kg N ha^{-1})	1.41	0.86
4	T4: 25 kg N (compost)	1.61	0.98
5	T5: 15 kg N (compost) + 10 kg N ha^{-1} (inorganic)	1.45	0.88
6	T6: 15 kg N (compost) + 20 kg N ha^{-1} (inorganic)	1.47	0.89
7	T7: 15 kg N (green leaf) + 10 kg N ha^{-1} (inorganic)	1.46	0.88
8	T8: 15 kg N (green leaf) + 20 kg N ha^{-1} (inorganic)	1.32	0.80
9	T9: 15 kg N (compost) + 10 kg N ha^{-1} (green leaf)	1.61	0.98
	CD @ 0.05	0.08	0.05

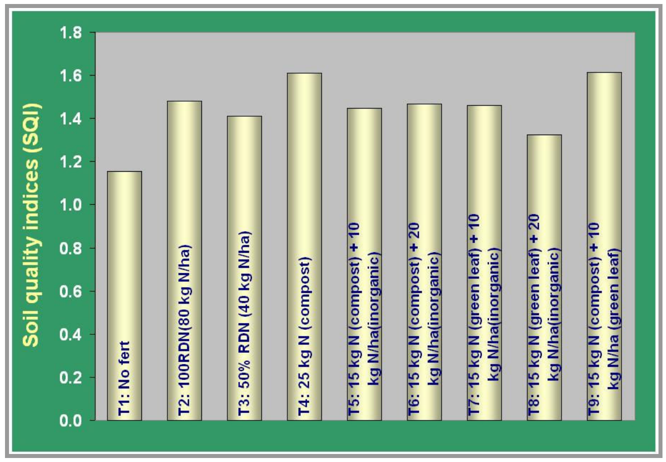


Fig 76: Soil quality indices as influenced by different soil-nutrient management (INM) treatments in maize-wheat based cropping sequence at Ballowal Saunkhri

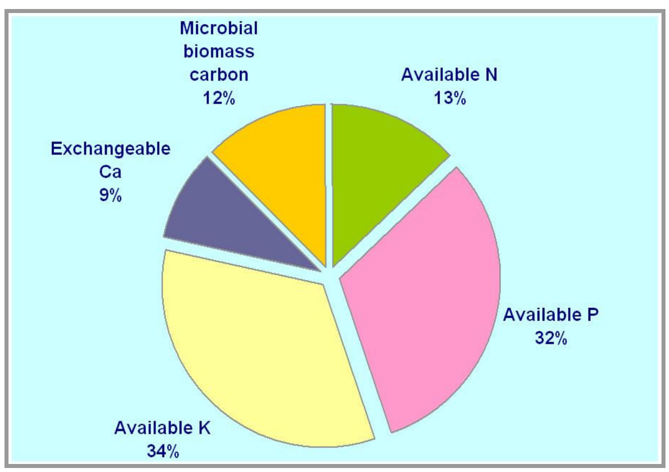


Fig 77: Percent contributions of key soil quality indicators towards soil quality indices as influenced by different soil-nutrient management (INM) treatments in maize-wheat based cropping sequence at Ballowal Saunkhri

4.2.22. Experiment 2: Effect of tillage and sources of nitrogen on the crop productivity in maize-wheat cropping sequence under dryland conditions

Another long-term experiment adopted at Ballowal Saunkhri (Hoshiarpur) for soil quality assessment study comprised of soil management components such as tillage, weed control measures and application of nitrogen through organic and /or inorganic sources. This experiment was initiated during kharif 2000 with maize-wheat cropping sequence. The soils of the experimental field were initially sandy loam in texture, slightly alkaline in reaction, low in organic carbon and available nitrogen and medium in available phosphorus. Nine treatments combinations comprising of three tillage practices viz., T1 – Conventional tillage (two ploughings + two preparatory cultivations + two plankings) along with interculture (IC), T2 – 50% conventional tillage along with interculture and T3- 50% conventional tillage + interculture along with herbicide application as main plot treatments and three nitrogen application sources viz., F1- 100% of the recommended nitrogen through organic source, F2 – 50% of the recommended nitrogen through organic source + 50% through inorganic source and F3- 100% of the recommended nitrogen through inorganic source as sub plot treatments, were laid out in split plot design with three replications in both the seasons.

Soil quality assessment studies were taken up in this experiment after 5 years of experimentation and the data on the soil quality parameters analyzed are presented in Tables 90 to 92.

The soils of the experimental plot were found to be slightly alkaline to alkaline in reaction and pH varied from 7.49 to 8.58. Tillage did not show significant influence on the pH of the soils but the fertilizer treatments and the interaction effect of tillage and fertilizer (tillage x fertilizer) treatments had significant influence on the soil reaction. Among all the treatments, 50 % CT + IC + 100% N (inorganic source) recorded the lowest pH of 7.49, while 50 % CT + IC + 50% N (organic) + 50 % inorganic source) recorded the highest pH of 8.58. Electrical conductivity of the soil varied between 0.16 to 0.19 dS m^{-1} across the treatments.

Organic carbon in soils as influenced by management treatments varied between 5.04 to 7.89 g kg^{-1}. Tillage had significant influence on the organic carbon treatments, where conventional tillage + interculture (CT + IC) recorded the highest organic carbon content of 7.57 g kg^{-1} which was at par with that of 50% conventional tillage + interculture along with herbicide application (50 % CT + IC + CWC) (7.09 g kg^{-1}). On an average, the fertilizer treatments also significantly influenced the organic carbon content of the experimental soils where 50% N (organic) + 50 % inorganic source) recorded significantly higher amount of organic carbon (7.01 g kg^{-1}) which was at par with 100% N (inorganic source) (6.56 g kg^{-1}) and 100% N (organic source/compost) (6.51 g kg^{-1}). However among all the treatments, CT + IC + 100% N (inorganic source) recorded significantly highest amount of organic carbon content of 7.89 g kg^{-1} which was at par with 50 % CT + IC + CWC + 50% N (organic) + 50 % inorganic source) (7.75 g kg^{-1}).

Available nitrogen in these soils varied from 128.23 to 162.14 kg ha^{-1} across the treatments. Despite, improved management treatments, these values were considerably low compared to the critical limits suggested for Indian conditions. Among the management treatments, tillage did not show any significant influence on available N, while the fertilizer treatments had the significant effect. Among the fertilizer treatments, 100% N (organic source/compost) recorded significantly highest available nitrogen of 150.65 kg ha^{-1} which was at par with 100% N (inorganic source) (146.38 kg ha^{-1}). However, among all the treatments, 50 % CT + IC + 100% N (organic source/compost) recorded the highest available nitrogen content of 162.14 kg ha^{-1} which was at par with CT + IC + 100% N (organic source/compost) (161.45 kg ha^{-1}), while the lowest amount was observed under CT + IC + 50% N (organic) + 50 % inorganic source) (128.23 kg ha^{-1}) (Fig 78).

Tillage alone and its interaction effect with fertilizer (Tillage x Fertilizer) did not show any significant influence on the available phosphorus content of the soils. However, the available phosphorus contents in the soils varied between 28.52 to 46.07 kg ha^{-1} across the treatments. Application of 100% organic sources resulted in higher available phosphorus (40.86 kg ha^{-1}) followed by 50% N (organic) + 50 % inorganic source) (36.44 kg ha^{-1}).

Available potassium in the soils was observed to be in the range of 164.9 to 237.6 kg ha^{-1} across the treatments (Fig 78). Tillage and the fertilizer treatments and their interactions had significant influence on available K status. When averaged over fertilizer treatments, among tillages, conventional tillage + interculture (CT + IC) recorded the highest available potassium content of 206.3 kg ha^{-1}. However, when averaged over tillage among the fertilizer treatments, highest available potassium was recorded under application of 100% organic sources (212.0 kg ha^{-1}).

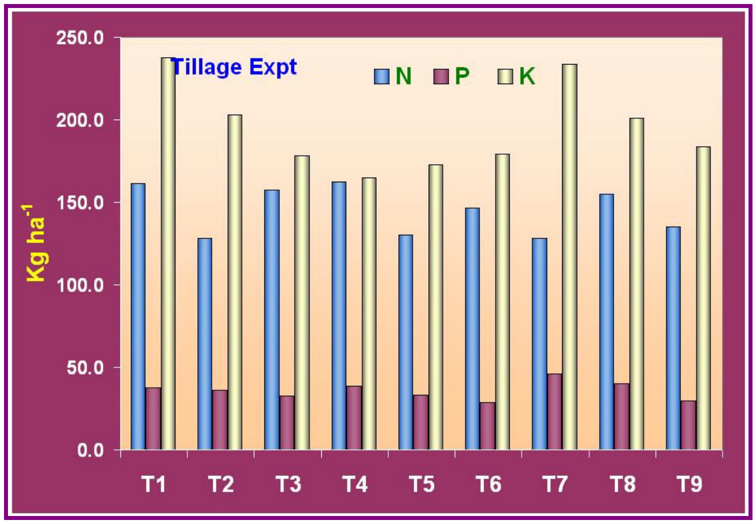


Fig 78: Effect of tillage and nutrient management treatments on chemical soil quality parameters (macronutrients) under maize-wheat cropping sequence in Inceptisols of Ballowal Saunkhri

Similar to potassium, exchangeable calcium content in the soils was significantly influenced by the tillage and fertilizer treatments alone but not by their interaction effects. However, exchangeable calcium in the soils ranged from 6.07 to 8.55 c mol kg^{-1} across the treatments. However, while comparing average effects, among the tillage and fertilizer treatments, 50 % CT + IC and application of 100% inorganic fertilizer sources resulted in higher exchangeable calcium in the soils. Exchangeable magnesium and available sulphur in the soils ranged between 0.48 to 1.09 cmol kg^{-1} and 11.08 to 16.60 kg ha^{-1} respectively. Only tillage practices showed a significant influence on exchangeable magnesium and available sulphur in the soils while the fertilizer treatments and the interaction effects of tillage and fertilizer had no significant influence on their availability.

Among the micronutrients, DTPA extractable zinc varied between 0.55 to 0.91 μg g^{-1} and was not influenced by management practices followed. Iron and manganese were significantly influenced by the tillage treatments alone. But no effect was recorded due to fertilizer treatment and their interaction with tillages. However, DTPA extractable Fe and Mn ranged between 4.08 to 6.62 μg g^{-1} and 6.32 to 11.50 μg g^{-1} respectively across the treatments. When averaged over fertilizer treatments, among the tillages, conventional tillage + interculture (CT + IC) recorded significantly highest DTPA extractable Fe and Mn in the soils. Copper and DTPA-sorbitol extractable B in the soils varied between 0.31 to 0.47 and 1.15 to 1.28 μg g^{-1} respectively (Table 91 & Fig 78a).

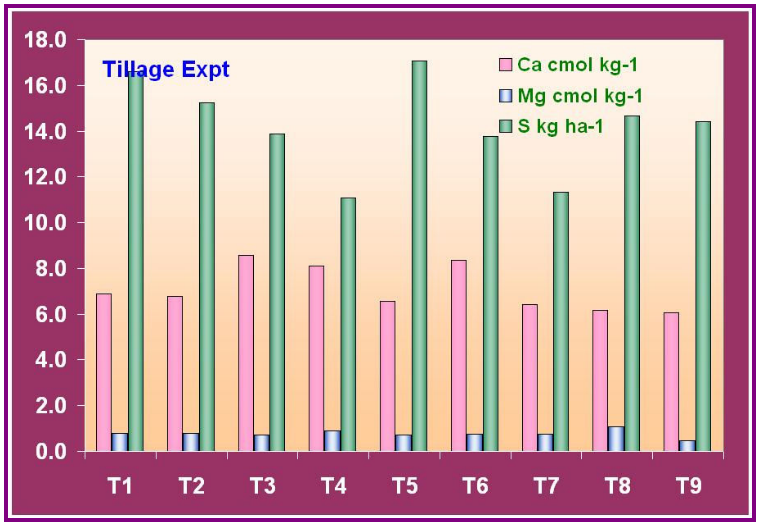


Fig 78a: Effect of tillage and nutrient management treatments on chemical soil quality parameters (secondary nutrients) under maize-wheat cropping sequence in Inceptisols of Ballowal Saunkhri

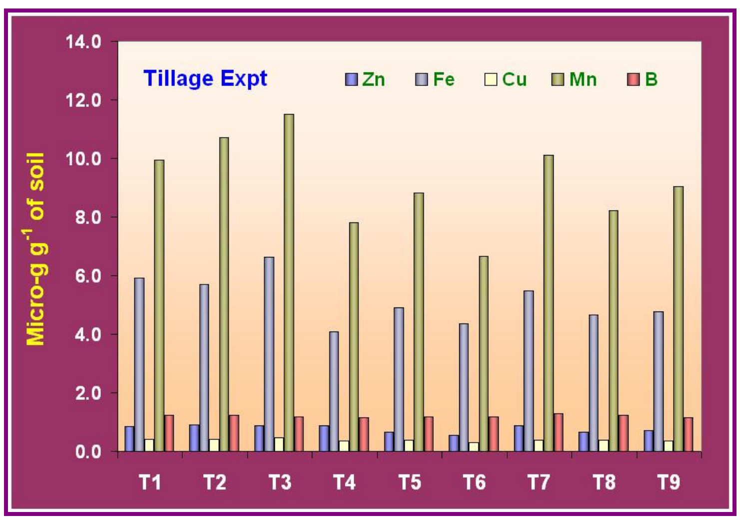


Fig 79: Effect of tillage and nutrient management treatments on chemical soil quality parameters (micronutrients) under maize-wheat cropping sequence in Inceptisols of Ballowal Saunkhri

The biological soil quality parameters viz., dehydrogenase assay, microbial biomass carbon and labile carbon were not significantly influenced by any of the management treatments except labile carbon where fertilizer treatments had a significant influence. However, dehydrogenase activity in the soil varied between 2.48 to 3.74 µg TPF $hr^{-1}g^{-1}$ soil, microbial biomass carbon from 119.7 to 155.8 µg g^{-1} soil and labile carbon from 336.6 to 370.7 µg g^{-1} soil. Irrespective of the level of significance, CT + IC + 50% N (organic) + 50 % inorganic source recorded the highest microbial biomass carbon and labile carbon of 155.8 and 370.7 µg g^{-1} of soil respectively (Fig 80).

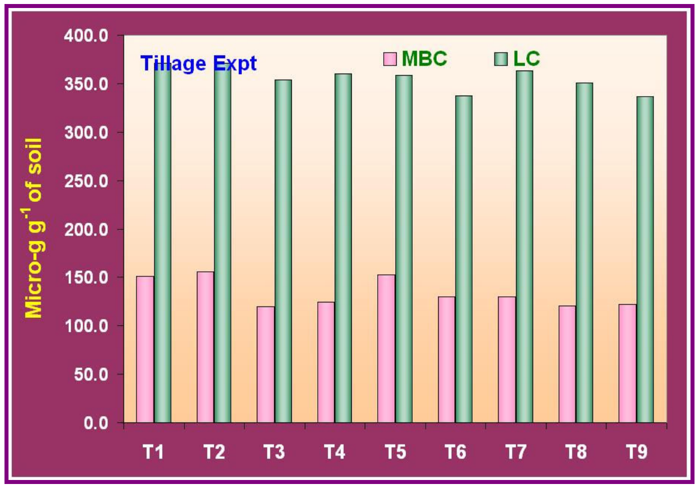


Fig 80: Effect of tillage and nutrient management treatments on biological soil quality parameters under Maize-Wheat cropping sequence in Inceptisols of Ballowal Saunkhri

Among the physical soil quality parameters, bulk density of the soils ranged from 1.38 to 1.50 Mg m^{-3} and was not significantly influenced by any of the management treatments. Mean weight diameter of the soil varied from 0.25 to 0.37 mm across the treatments, and was significantly influenced only by the tillage practices where conventional tillage + interculture (CT + IC) recorded significantly highest mean weight diameter of 0.34 mm.

Table 90: Effect of tillage and nutrient management treatments on soil chemical characteristics under Maize-Wheat cropping sequence in Inceptisols of Ballowal Saunkhri

Sno	Name of the treatments	pH	EC ($dS\ m^{-1}$)	OC ($g\ kg^{-1}$)	N ($kg\ ha^{-1}$)	P ($kg\ ha^{-1}$)	K ($kg\ ha^{-1}$)
1	CT + IC + 100% N (organic source/compost)	7.92	0.19	7.55	161.5	37.8	237.6
2	CT + IC + 50% N (organic) + 50 % inorganic source)	7.88	0.19	7.25	128.2	25.9	203.0
3	CT + IC + 100% N (inorganic source)	8.36	0.19	7.89	157.4	32.7	178.3
4	50 % CT + IC + 100% N (organic source/compost)	7.61	0.16	5.04	162.1	38.7	164.6
5	50 % CT + IC + 50% N (organic) + 50 % inorganic source)	8.58	0.17	5.98	130.4	33.3	172.6
6	50 % CT + IC + 100% N (inorganic source)	7.49	0.17	5.21	146.7	28.5	179.3
7	50 % CT + IC + CWC+ 100% N (organic source/compost)	8.20	0.19	6.93	128.4	46.1	233.6
8	50 % CT + IC + CWC + 50% N (organic) + 50 % inorganic source)	8.35	0.17	7.75	155.1	40.1	201.0
9	50 % CT + IC + CWC + 100% N (inorganic source)	8.22	0.16	6.56	135.1	29.9	183.0
	Between two main treatment means	NS	0.02	0.5	NS	NS	9.93
	Between two sub treatment means	0.27	NS	0.4	7.20	5.42	19.4
	Between two sub-treatment means at same main treatments	0.46	NS	0.7	12.5	NS	33.6
	Between two main treatment means at same or different sub treatments	0.48	NS	0.7	17.5	NS	28.5

Table 91: Effect of tillage and nutrient management treatments on soil chemical characteristics under Maize-Wheat cropping sequence in Inceptisols of Ballowal Saunkhri

Sno	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		(cmol kg^{-1})		(kg ha^{-1})			µg g^{-1}		
1	CT + IC + 100% N (organic source/compost)	6.89	0.79	16.6	0.85	5.91	0.42	9.95	1.23
2	CT + IC + 50% N (organic) + 50 % inorganic source)	6.77	0.80	15.3	0.91	5.69	0.42	10.7	1.25
3	CT + IC + 100% N (inorganic source)	8.55	0.73	13.9	0.88	6.62	0.47	11.5	1.17
4	50 % CT + IC + 100% N (organic source/compost)	8.10	0.89	11.1	0.89	4.08	0.36	7.82	1.15
5	50 % CT + IC + 50% N (organic) + 50 % inorganic source)	6.55	0.73	17.1	0.67	4.91	0.37	8.81	1.18
6	50 % CT + IC + 100% N (inorganic source)	8.37	0.74	13.8	0.55	4.37	0.31	6.32	1.18
7	50 % CT + IC + CWC+ 100% N (organic source/compost)	6.42	0.74	11.3	0.88	5.47	0.38	10.1	1.28
8	50 % CT + IC + CWC + 50% N (organic) + 50 % inorganic source)	6.15	1.09	14.7	0.66	4.66	0.39	8.21	1.22
9	50 % CT + IC + CWC + 100% N (inorganic source)	6.07	0.48	14.4	0.72	4.76	0.35	9.03	1.15
	Between two main treatment means	0.95	NS	NS	NS	0.72	0.05	1.69	NS
	Between two sub treatment means	0.76	0.10	1.81	NS	NS	NS	NS	0.04
	Between two sub-treatment means at same main treatments	NS	0.18	3.13	NS	NS	0.05	NS	NS
	Between two main treatment means at same or different sub treatments	NS	0.15	2.99	NS	NS	0.06	NS	NS

Table 92: Effect of tillage and nutrient management treatments on physical and biological parameters under Maize-Wheat cropping sequence in Inceptisols of Ballowal Saunkhri

		DHA (μg TPF $hr^{-1}g^{-1}$)	MBC (μg g^{-1} of soil)	LC (μg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	CT + IC + 100% N (organic source/compost)	3.34	151.1	371.1	1.48	0.35
2	CT + IC + 50% N (organic) + 50 % inorganic source)	3.59	155.8	370.7	1.38	0.30
3	CT + IC + 100% N (inorganic source)	2.98	119.7	353.9	1.52	0.37
4	50 % CT + IC + 100% N (organic source/compost)	2.48	124.1	360.5	1.50	0.26
5	50 % CT + IC + 50% N (organic) + 50 % inorganic source)	2.58	152.9	358.3	1.43	0.26
6	50 % CT + IC + 100% N (inorganic source)	2.70	129.9	337.6	1.47	0.25
7	50 % CT + IC + CWC+ 100% N (organic source/compost)	3.74	129.8	363.0	1.44	0.27
8	50 % CT + IC + CWC + 50% N (organic) + 50 % inorganic source)	3.15	120.4	350.6	1.47	0.32
9	50 % CT + IC + CWC + 100% N (inorganic source)	3.07	122.3	336.6	1.47	0.26
	Between two main treatment means	NS	NS	NS	NS	0.04
	Between two sub treatment means	NS	NS	16.6	NS	NS
	Between two sub-treatment means at same main treatments	NS	NS	NS	NS	NS
	Between two main treatment means at same or different sub treatments	NS	NS	NS	NS	NS

4.2.22.1. Key indicators and soil quality assessment

4.2.22.2. Results of principal component analysis

Data pertaining to the influence of different tillage and soil-nutrient management treatments under maize-wheat cropping sequence on 19 soil quality indices has been statistically analyzed and it was observed that out of 19 soil quality parameters, 4 variables viz., available Zn, dehydrogenase assay, microbial biomass carbon and bulk density were insignificant and hence were dropped from further PCA analysis. In the PCA of 15 variables, five PCs had eigen values >1 and explained 76.4

% variance in the data set (Table 93). In PC1, PC3 and PC5, only single variables viz., organic carbon, available N, and electrical conductivity have been qualified as the highly weighted variables respectively, as were retained for the final MDS. In PC2 and PC4, two variables each were qualified as highly weighted variables. In PC2, available P and exchangeable Mg were highly weighted with correlation value of 0.449* which was less than 0.70 and hence were retained for the final MDS (Table 94). Even in PC4, pH and available S being the highly weighted variables had correlation of 0.428* and were retained for the final MDS. Hence, all the variables which were qualified in all the PCs had to be retained for the MDS and no variable were eliminated. The final variables retained for the final MDS included seven variables viz., pH, electrical conductivity, organic carbon, available N, available P, exchangeable Mg and available S and were termed the key indicators for different tillage and soil-nutrient management treatments under maize-wheat cropping sequence in Inceptisols of Ballowal Saunkhri, Hoshiarpur. It was surprised to make out that this final MDS did not include any of the biological as well as physical soil quality parameters.

Table 93: Principal component analysis of soil quality parameters as influenced by different tillage and soil-nutrient management treatments under maize-wheat cropping sequence in Inceptisols of Ballowal Saunkhri, Hoshiarpur

	PC1	PC2	PC3	PC4	PC5
Total Eigen values	4.582	2.264	1.978	1.560	1.083
% of Variance	30.544	15.096	13.186	10.401	7.217
Cumulative %	20.544	45.640	58.826	69.228	76.444
Eigen Vectors					
pH	0.413	-0.371	-0.021	**0.587**	-0.268
EC	0.572	-0.045	0.018	-0.200	**0.704**
OC	**0.872**	-0.082	0.124	0.220	0.090
N	-0.072	0.276	**0.795**	0.015	0.091
P	0.434	**0.696**	-0.354	0.077	-0.298
K	0.697	0.284	-0.339	0.072	0.308
Ca	-0.155	0.390	0.586	-0.388	0.054
Mg	0.163	**0.676**	0.267	0.338	0.148
S	0.169	-0.503	0.211	**0.636**	0.249
Fe	0.775	-0.344	0.066	-0.406	0.027
Cu	0.763	-0.084	0.312	-0.188	-0.298
Mn	0.708	-0.330	-0.037	-0.426	-0.261
B	0.533	0.313	-0.513	-0.056	0.111
LC	0.342	0.529	0.010	0.207	-0.175
MWD	0.693	0.031	0.514	0.136	-0.166

Table 94: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs	P	Mg
PC1		
P	1.00	0.449*
Mg	0.449*	1.00
Correlation sum	1.449	1.449
PC2	pH	S
pH	1.00	0.428*
S	0.428*	1.00
Correlation sum	1.428	1.428

*correlation is significant at P = 0.05 level

4.2.22.3. Soil quality indices

Soil quality indices were computed using seven key soil quality indicators viz., pH, electrical conductivity, organic carbon, available N, available P, exchangeable Mg and available S. The soil quality indices varied from 0.96 to 1.19 across the tillage and nutrient management treatments (Table 95). The soil quality indices, when reduced to a scale of one, termed as 'relative soil quality indices' (RSQI) varied between 0.80 and 0.99 (Fig 81). From the data, it was observed that among tillage, nutrient management treatments as well as their interaction effects had significant influence on soil quality indices. Among the tillage treatments, practice of conventional tillage + one interculture maintained significantly highest soil quality with SQI of 1.12 which was almost at par with practice of 50% CT + one interculture + chemical weed control (1.08). Among the nutrient management treatments, application of nutrients through 50% N (organic) + 50 % (inorganic) source maintained higher soil quality with SQI of 1.10 followed by application of 100% organics (1.08). Of all the treatments, 50 % CT + IC + CWC + 50% N (organic) + 50 % (inorganic) source maintained highest soil quality with SQI of 1.19 which was at par with CT + IC + 100% N (organic source/compost) (1.16). The average percent contribution of key indicators towards soil quality indices was: pH (12%), electrical conductivity (6%), organic carbon (31%), available N (14%), available P (14%), exchangeable Mg (13%) and available S (10%) (Fig 82).

Table 95: Soil quality indices and relative soil quality indices under different tillage and soil-nutrient management treatments in maize-wheat cropping sequence in Inceptisols of Ballowal Saunkhri

		SQI	RSQI
1	CT + IC + 100% N (organic source/compost)	1.16	0.96
2	CT + IC + 50% N (organic) + 50 % inorganic source)	1.09	0.91
3	CT + IC + 100% N (inorganic source)	1.11	0.92
4	50 % CT + IC + 100% N (organic source/compost)	1.01	0.83
5	50 % CT + IC + 50% N (organic) + 50 % inorganic source)	1.00	0.83
6	50 % CT + IC + 100% N (inorganic source)	0.96	0.80
7	50 % CT + IC + CWC+ 100% N (organic source/compost)	1.07	0.89
8	50 % CT + IC + CWC + 50% N (organic) + 50 % inorganic source)	1.19	0.99
9	50 % CT + IC + CWC + 100% N (inorganic source)	0.96	0.80
	Between two main treatment means	0.05	0.04
	Between two sub treatment means	0.04	0.03
	Between two sub-treatment means at same main treatments	0.07	0.06
	Between two main treatment means at same or different sub treatments	0.07	0.06

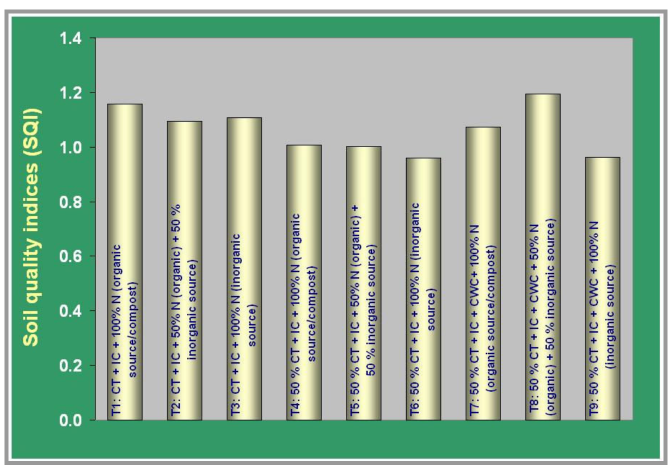


Fig 81: Soil quality indices under different tillage and soil-nutrient management treatments in maize-wheat cropping sequence at Ballowal Saunkhri

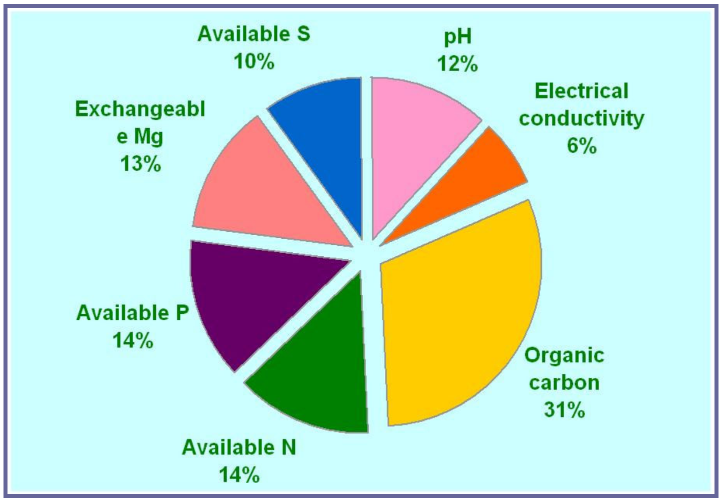


Fig 82: Percent contributions of key soil quality indicators towards soil quality indices under different tillage and soil-nutrient management treatments in maize-wheat cropping sequence at Ballowal Saunkhri

4.2.23. Experiment 3: Assessment of soil quality in farmer's fields at Ballowal Saunkhri centre

Soil samples received from different land use system from farmer's field of Ballowal Saunkhri were also assessed for soil quality parameters. The list of predominant systems studied is given below.

List of predominant agricultural systems studied from farmer's field.

i. Pearlmillet-oilseed

ii. Maize-Wheat

iii. Agro-horti (Peach): gnut/wheat/barley/taramira

iv. Agro-horti (Guava): gnut/wheat/barley/lentil-guava

v. Agro-forestry (Dhek): gnut/wheat/lentil/taramira

vi. Agro-forestry (Dhek): gnut/blackgram, bajra (F)

In all, soil samples were analyzed for 19 soil quality indicators using three laboratory replicates of each sample. The data are presented in Tables 96 to 98. The soil reaction of the farmers fields of this area were found to be in slightly alkaline range and pH varied from 7.53 to 8.05 across the six-land use systems. Electrical conductivity of the soil was very low and ranged from 0.10 to 0.16 dS m^{-1}. Among all the land use systems in the farmer's fields, maize-wheat system recorded significantly highest soil pH and electrical conductivity of 8.05 and 0.16 dS m^{-1} respectively. While, lowest values recorded pH 7.53 and EC 0.10 dS m^{-1} were under pearl millet-oilseed system.

The organic carbon content under these systems varied from 3.83 (Pearl millet-Oilseed) to 6.69 g kg^{-1} (Maize-Wheat). However, the available nitrogen in soil under these systems was considerably low and varied between 114.8 (Pearl millet-Oilseed) to 133.1 kg ha^{-1} (Maize-Wheat). Maize-wheat system recorded the highest available nitrogen content of 133.1 kg ha^{-1} which was at par with that of Agro-forestry (Dhek): gnut / blackgram, bajra (F) (132.6 kg ha^{-1}). Available phosphorus and potassium contents of the soils in the farmer's fields were found to be in the range of 12.6 to 26.0 kg ha^{-1} and 76.1 to 146.6 respectively. These two nutrients were found highest in Maize –wheat system. Considering the critical limits for both the nutrients, soils under these systems, on an average basis, were found low to medium in phosphorus and low in potassium. Hence, it is important to supplement potassium in these soils through potassic fertilizer depending upon the land use system and their removal rate. Among the secondary nutrients, available sulphur content was significantly influenced by the systems and varied from 10.5 (Pearl millet-Oilseed) to 13.1 (Maize-Wheat) kg ha^{-1}. These values are much below the critical limit (20 kg ha^{-1}) set for sulphur under Indian conditions. The amount of Ca and Mg was also significantly influenced by land use systems. However, the contents of these nutrients were adequate. The soil micronutrient contents were significantly influenced by the management treatments. Among all the different land use systems practiced in farmer's field, Maize-Wheat system recorded significantly highest contents of Zn (0.58), Fe (7.81), Cu (0.48) Mn (12.7) and B (1.02) μg g^{-1} of soil. Among the biological soil quality indicators, microbial biomass carbon and dehydrogenase assay significantly varied under different land use systems. However, no such significant variation was observed in case of 0.01 M $KMnO_4$ extractable labile carbon. Among the two predominant physical soil quality indicators assessed, significant variation was recorded in bulk density under different land use systems. However, mean weight diameter of soil aggregates was not significantly influenced.

Table 96: Assessment of soil quality indicators under different land use systems in farmer's field at Ballowal Saunkhri (Hoshiarpur) - Physico-chemical and macronutrients

		pH	EC (dS m^{-1})	OC (g kg^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
1	Pearlmillet- Oilseed	7.53	0.10	3.83	114.8	14.1	76.0
2	Maize- Wheat	8.05	0.16	6.69	133.1	26.0	146.6
3	Agri-Horti (Peach): Gnut/Barley/Wheat /Taramira)	7.55	0.12	5.98	122.5	24.4	81.9
4	Agri-Horti (Guava): Gnut/Barley/Wheat /Lentil-Guava)	7.92	0.11	3.93	115.9	12.6	101.7
5	Agroforestry (Dhek): Gnut/Wheat/Lentil/Taramira	7.75	0.11	4.59	116.7	24.6	95.2
6	Agroforestry (Dhek): Gnut/Blackgram/Bajra (F)	7.63	0.12	4.63	132.6	16.2	93.8
	CD @ 0.05	0.25	0.03	0.54	13.5	5.46	15.8

Table 97: Assessment of soil quality indicators under different land use systems in farmer's field at Ballowal Saunkhri (Hoshiarpur)-Secondary and micronutrients

		Ca	Mg	S	Zn	Fe	Cu	Mn	B
		C mol kg^{-1}		(kg ha^{-1})			μg g^{-1}		
1	Pearlmillet- Oilseed	4.70	0.86	10.5	0.46	6.64	0.32	11.8	0.69
2	Maize- Wheat	7.20	1.65	13.1	0.58	7.81	0.48	12.7	1.02
3	Agri-Horti (Peach): Gnut/Barley/Wheat /Taramira)	6.15	2.17	12.7	0.48	5.29	0.29	7.23	0.79
4	Agri-Horti (Guava): Gnut/Barley/Wheat /Lentil-Guava)	7.81	1.81	13.2	0.53	5.81	0.32	7.65	0.86
5	Agroforestry (Dhek): Gnut/Wheat/Lentil/Taramira	6.12	1.65	12.7	0.80	6.37	0.38	8.16	0.85
6	Agroforestry (Dhek): Gnut/Blackgram/Bajra (F)	3.10	0.64	13.7	0.39	5.37	0.28	4.90	0.83
	CD @ 0.05	0.96	0.15	1.38	0.09	0.91	0.08	1.09	0.09

Table 98: Assessment of soil quality indicators under different land use systems in farmer's field at Ballowal Saunkhri (Hoshiarpur)-physical and biological properties

		DHA (μg TPF $hr^{-1}g^{-1}$)	MBC (μg g^{-1} of soil)	LC (μg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	Pearlmillet- Oilseed	1.68	146.4	337.6	1.40	0.22
2	Maize- Wheat	2.88	147.1	358.4	1.51	0.25
3	Agri-Horti (Peach): Gnut/Barley/Wheat /Taramira)	2.68	161.4	343.3	1.51	0.23
4	Agri-Horti (Guava): Gnut/Barley/Wheat/Lentil-Guava)	1.94	138.4	368.1	1.55	0.22
5	Agroforestry (Dhek): Gnut/Wheat/Lentil/Taramira	2.19	123.4	376.3	1.56	0.26
6	Agroforestry (Dhek): Gnut/Blackgram/Bajra (F)	2.29	129.6	371.9	1.55	0.25
	CD @ 0.05	0.47	8.81	NS	0.08	NS

4.2.23.1. Key indicators and soil quality assessment

4.2.23.2. Results of principal component analysis

Data pertaining to the influence of various cropping systems practiced under farmers fields on 19 soil quality indices has been statistically analyzed and it was observed that out of 19 soil quality parameters, only two variables viz., labile carbon and mean weight diameter were insignificant and hence were dropped from further PCA analysis. In the PCA of 17 variables, five PCs had eigen values >1 and explained 88.0 % variance in the data set (Table 99). In PC1, three variables viz., available K, available Cu and available B were the highly weighted variables. In PC2, only two variables were highly weighted viz., available S and available Mn. Again in PC3, two variables were highly weighted viz., available N and available Zn. In PC4, only one variable was highly weighted ie exchangeable Mg while in PC5, again two variables viz., available P and available Zn were highly weighted. The correlation analysis run between the variables individually under PC1 showed that the correlations were significant and the variables were also well correlated (>0.70) (Table 100). Available K having the highest correlation sum has been retained fro the final MDS. Among available Cu and B, as both were well correlated with each other, available B was retained for the final MDS while available Cu was eliminated. In the rest of the PCs, the correlations analysis run between two variables qualified respectively under PC had no significant correlations and hence all the variables qualified in rest of the PCs were retained for the final MDS. Hence, the final MDS included available N, available P, available K, exchangeable Mg, available S, Available Zn, available Mn and available B and were termed the key indicators for different cropping systems practiced in farmer's fields in Inceptisols of Ballowal Saunkhri, Hoshiarpur. It was surprised to observe that this MDS did not include any of the biological or physical soil quality indicators.

Table 99: Principal component analysis of soil quality parameters as influenced by different cropping systems under farmers fields at Ballowal Saunkhri (Hoshiarpur)

	PC1	PC2	PC3	PC4	PC5
Total Eigen values	6.652	2.906	2.337	1.945	1.116
% of Variance	39.132	17.092	13.749	11.443	6.565
Cumulative %	39.132	56.224	69.973	71.416	87.981
Eigen Vectors					
pH	0.676	-0.024	0.351	-0.205	0.358
EC	0.756	0.027	-0.267	-0.1151	0.114
OC	0.794	0.143	-0.462	0.226	-0.081
N	0.364	0.262	**-0.643**	-0.361	-0.119
P	0.678	0.014	-0.141	0.260	**-0.565**
K	**0.897**	-0.026	-0.009	-0.308	0.188
Ca	0.568	-0.206	0.495	0.466	0.296
Mg	0.496	0.093	0.234	**0.794**	0.012
S	0.415	**0.814**	0.089	-0.116	0.176
Zn	0.420	-0.132	**0.663**	0.068	**-0.562**
Fe	0.629	-0.638	0.060	-0.309	-0.009
Cu	**0.836**	-0.330	0.163	-0.238	-0.093
Mn	0.449	**-0.860**	-0.059	-0.067	0.076
B	**0.848**	0.266	0.082	-0.177	0.139
DHA	0.759	0.335	-0.422	0.161	-0.181
MBC	0.122	-0.272	-0.556	0.682	0.309
BD	0.271	0.756	0.472	0.025	0.052

Table 100: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs	K	Cu	B
PC 1			
K	1.00	0.817**	0.820**
Cu	0.817**	1.00	0.629**
B	0.820**	0.629**	1.00
Correlation sum	**2.637**	**2.446**	**2.449**
PC 2	S	Mn	
S	1.00	-0.471	
Mn	-0.471	1.00	
Correlation Sum	**1.471**	**1.471**	
PC3	N	Zn	
N	1.00	-0.226	
Zn	-0.226	1.00	
Correlation Sum	**1.226**	**1.226**	
PC5	P	Zn	
P	1.00	0.460	
Zn	0.460	1.00	
Correlation Sum	**1.460**	**1.460**	

*correlation is significant at P = 0.05 level

**correlation is significant at P = 0.01 level

4.2.23.3. Soil quality indices

Soil quality indices were computed using seven key soil quality indicators viz., available N, available P, available K, exchangeable Mg, available S, Available Zn, available Mn and available B. The soil quality indices varied from 1.11 to 1.61 across the farmer's fields (Table 101). The soil quality indices, when reduced to a scale of one, termed as 'relative soil quality indices' (RSQI) varied between 0.67 to 0.98 (Fig 83). From the data, it was observed that maize-wheat system maintained the highest soil quality with SQI value of 1.61 followed by agroforestry (dhek) system (1.35). Irrespective of their statistical significance, the relative order of performance of the cropping systems in influencing soil quality in terms of SQI was: Maize- Wheat (1.61) > Agroforestry (Dhek) - Gnut/ Wheat/ Lentil/ Taramira (1.35) > Agri-Horti (Guava)- Gnut/ Barley/ Wheat / Lentil-Guava) (1.29) > Agri-Horti (Peach)- Gnut/Barley/Wheat /Taramira) (1.24) > Agroforestry (Dhek)- Gnut/ Blackgram/ Bajra (F) (1.16) > Pearlmillet- Oilseed (1.11). The average percent contribution of key indicators towards soil quality indices was: available N (11%), available P (4%), available K (22%), exchangeable Mg (7%), available S (12%), Available Zn (8%), available Mn (10%) and available B (26%) (Fig 84). Of all these indicators, available B contributed more to SQI followed by available K in these soils.

Table 101: Soil quality indices under different land use systems in farmer's field at Ballowal Saunkhri (Hoshiarpur)

		SQI	RSQI
1	Pearlmillet- Oilseed	1.11	0.67
2	Maize- Wheat	1.61	0.98
3	Agri-Horti (Peach): Gnut/Barley/Wheat /Taramira)	1.24	0.75
4	Agri-Horti (Guava): Gnut/Barley/Wheat /Lentil-Guava)	1.29	0.78
5	Agroforestry (Dhek): Gnut/Wheat/Lentil/Taramira	1.35	0.82
6	Agroforestry (Dhek): Gnut/Blackgram/Bajra (F)	1.16	0.70
	CD @ 0.05	0.08	0.05

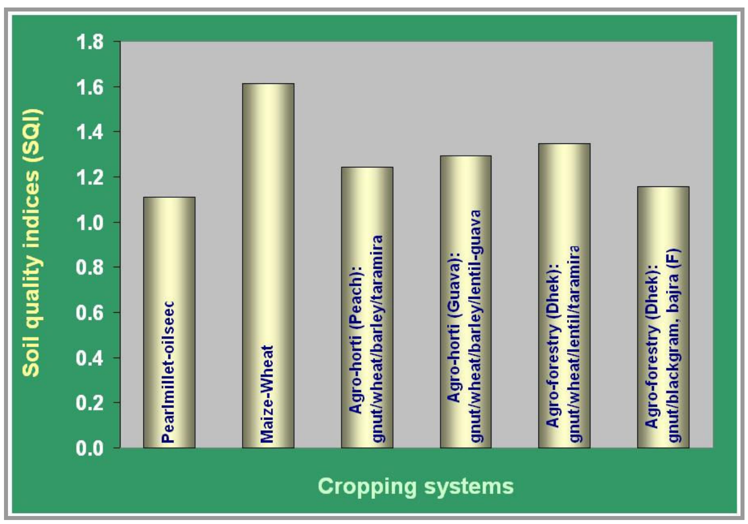


Fig 83: Soil quality indices under different land use systems in farmer's field at Ballowal Saunkhri (Hoshiarpur)

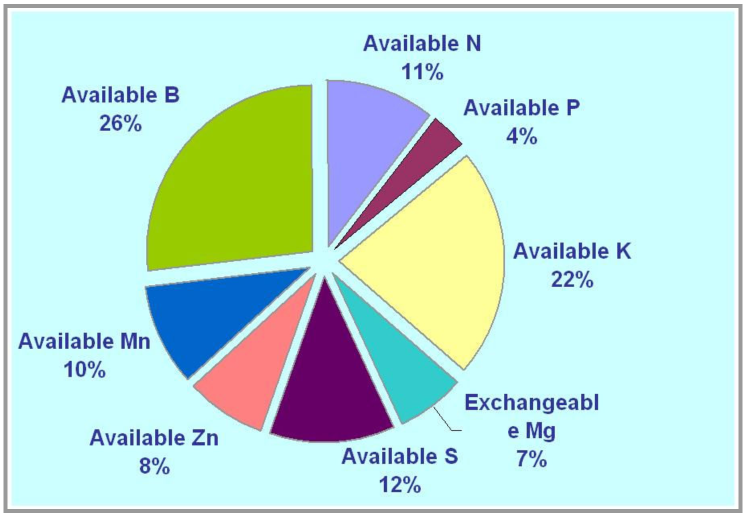


Fig 84: Percent contributions of key soil quality indictors towards soil quality indices under different land use systems in farmer's field at Ballowal Saunkhri (Hoshiarpur)

Table 102: Summary of soil quality indices and relative soil quality indices as influenced by different soil nutrient management practices under different trials practiced in Inceptisols of Ballowal Saunkhri, Hoshiarpur.

Sno		SQI	RSQI
Experiment 1: Integrated nutrient management practices in maize/black gram – wheat/lentil cropping systems under rainfed semi-arid tropics			
1	T1: No Fertilizer	1.16	0.70
2	T2: 100% RDN (80 kg N ha^{-1})	1.48	0.90
3	T3: 50% RDN (80 kg N ha^{-1})	1.41	0.86
4	T4: 25 kg N (compost)	1.61	0.98
5	T5: 15 kg N (compost) + 10 kg N ha^{-1} (inorganic)	1.45	0.88
6	T6: 15 kg N (compost) + 20 kg N ha^{-1} (inorganic)	1.47	0.89
7	T7: 15 kg N (green leaf) + 10 kg N ha^{-1} (inorganic)	1.46	0.88
8	T8: 15 kg N (green leaf) + 20 kg N ha^{-1} (inorganic)	1.32	0.80
9	T9: 15 kg N (compost) + 10 kg N ha^{-1} (green leaf)	1.61	0.98
Experiment 2: Effect of tillage and sources of nitrogen on the crop productivity in maize-wheat cropping sequence under dryland conditions			
1	CT + IC + 100% N (organic source/compost)	1.16	0.96
2	CT + IC + 50% N (organic) + 50 % inorganic source)	1.09	0.91

Sno		SQI	RSQI
3	CT + IC + 100% N (inorganic source)	1.11	0.92
4	50 % CT + IC + 100% N (organic source/compost)	1.01	0.83
5	50 % CT + IC + 50% N (organic) + 50 % inorganic source)	1.00	0.83
6	50 % CT + IC + 100% N (inorganic source)	0.96	0.80
7	50 % CT + IC + CWC+ 100% N (organic source/compost)	1.07	0.89
8	50 % CT + IC + CWC + 50% N (organic) + 50 % inorganic source)	1.19	0.99
9	50 % CT + IC + CWC + 100% N (inorganic source)	0.96	0.80
Experiment 3: Land use systems at Farmers fields			
1	Pearlmillet- Oilseed	1.11	0.67
2	Maize- Wheat	1.61	0.98
3	Agri-Horti (Peach): Gnut/Barley/Wheat /Taramira)	1.24	0.75
4	Agri-Horti (Guava): Gnut/Barley/Wheat /Lentil-Guava)	1.29	0.78
5	Agroforestry (Dhek): Gnut/Wheat/Lentil/Taramira	1.35	0.82
6	Agroforestry (Dhek): Gnut/Blackgram/Bajra (F)	1.16	0.70

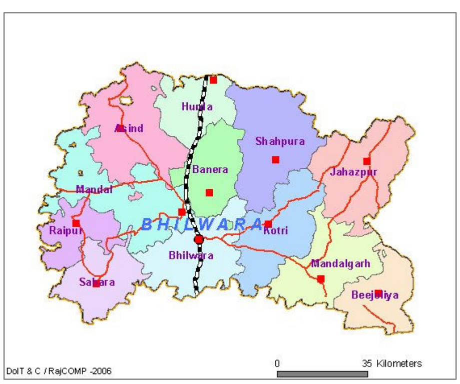
Table 103: Summary of key soil quality indicators, soil quality indices and the best soil nutrient management practices identified under different cropping systems in Inceptisols of Ballowal Saunkhri, Hoshiarpur.

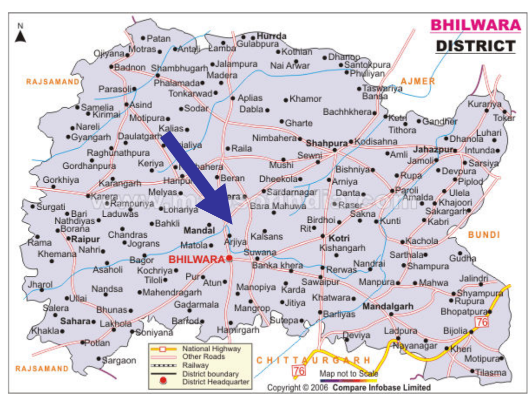
Sno	Key soil quality indicators and their % contribution	SQI	RSQI	Best management practices with higher SQI
Experiment 1: Integrated nutrient management practices in maize/black gram – wheat/lentil cropping systems under rainfed semi-arid tropics				
	• Available N (13%) • Available P (32%) • Available K (34%) • Exchangeable Ca (9%) • Microbial biomass carbon (12%)	1.16 - 1.61	0.70 – 0.98	1. Application of 25 kg N (compost) (1.61) 2. Application of 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) (1.61) 3. Application of 100% RDN (80 kg N ha^{-1}) (1.48)
Experiment 2: Effect of tillage and sources of nitrogen on the crop productivity in maize-wheat cropping sequence under dryland conditions				
	• Available Zn (63%) • Exchangeable Mg (13%) • Available Fe (11%) • Available P (7%)	0.96 – 1.19	0.80 – 0.99	Tillage treatments 1. Practice of conventional tillage + one interculture (1.12) 2. Practice of 50% CT + one interculture + chemical weed control (1.08).

Sno	Key soil quality indicators and their % contribution	SQI	RSQI	Best management practices with higher SQI
				Nutrient management treatments 3. Application of nutrients through 50% N (organic) + 50 % (inorganic) source (1.10) 4. Application of 100% organics (1.08). Of all treatments 5. Practice of 50 % CT + IC + CWC + 50% N (organic) + 50 % (inorganic) source (1.19)
Experiment 3: Land use systems at Farmers fields				
	• Available N (11%) • Available P (4%) • Available K (22%) • Exchangeable Mg (7%) • Available S (12%) • Available Zn (8%) • Available Mn (10%) • Available B (26%)	1.11 – 1.61	0.67 – 0.98	1. Maize- Wheat (1.61) 2. Agroforestry (Dhek) - Gnut/ Wheat/ Lentil/ Taramira (1.35) 3. Agri-Horti (Guava)- Gnut/ Barley/ Wheat / Lentil-Guava) (1.29) 4.

Arjia Centre

Maize based production system





4.2.24. Effect of predominant soil and nutrient management practices on soil quality indicators (attributes) and soil quality indices at Arjia centre of AICRPDA

Location description, climate and soil characteristics

Arjia is in north Gujarat (inclusion of Aravalli range and Rajasthan uplands) hot dry semi-arid eco-sub region (AESR 4.2). Annual potential evapo-transpiration of the region is 1681 mm whereas normal annual rainfall is 658 mm. Length of growing period in this region is 90-120 days. Maize is the preferred crop by farmers. Other important crops of the region are: sorghum, pigeon pea, green gram, groundnut, blackgram, cowpea, mustard, barley, chickpea, wheat, cotton, sunflower, castor etc. In this rainfed tract, drought occurs almost twice in five years. Water erosion is of high severity with moderate loss of topsoil, affecting 51-100% area. The soils are alluvium-derived deep loamy gray brown. Available water capacity is medium. Soil reaction is towards neutrality. Electrical conductivity is suitable for crop production. In general, soils are low in organic carbon, medium in phosphorus and low to medium in potassium. This centre sub-serves the research needs of Bhilwara, Chittorghar, Udaipur, Banswara, Rajsamand and parts of Ajmer.

In the present study, from this centre, the following two long-term experiments and farmers fields were adopted for assessing soil quality as influenced by different long-term soil, nutrient and other management practices being practiced.

- Experiment 1: Low till farming strategies for resources conservation and improving soil quality
- Experiment 2: Integrated nutrient supply system for rainfed semiarid tropics under maize, blackgram strip and block system
- Experiment 3: Farmers fields

4.2.25. Experiment 1: Low till farming strategies for resources conservation and improving soil quality

An experiment entitling "Low till farming strategies for resources conservation and improving soil quality" which was initiated during the year 2000 was chosen in order to work out the low tillage strategies, to identify the low cost INM treatment and to study the long term impact on soil quality. The experiment was laid in a split plot design with three tillage treatments viz., Conventional tillage+ twice weeding and hoeing (T1), Low tillage + herbicide + one weeding and hoeing (T2) and low tillage + twice weeding and hoeing (T3) and three nutrient management treatments viz., 100% inorganic fertilizer (F1), 100% organic fertilizer (compost) (F2) and 50% inorganic + 50% organic (compost) fertilizer (F3). Black gram (T-9) and Maize (Navjot) were used as the test crops. In the present study, a set of 9 treatments comprising of tillage and soil-nutrient management practices were evaluated for soil quality. Soil quality indices were computed after rigorous analysis of the soil samples collected from surface layer for 19 soil physical, chemical and biological indicators.

In this experiment, the soil quality assessment was taken up after five years of experimentation. The data on various soil quality indicators as influenced by the different treatments are presented in Tables 104 to 106 and Fig 85 to 87.

The tillage practices showed a significant influence on soil pH and EC, while the other treatments and their interaction effects did not show any significant influence on the soil pH and electrical conductivity. The pH of these soils ranged from 7.19 to 7.51 and was in the neutral to slightly alkaline range, while electrical conductivity varied from 0.18 to 0.26 dS m^{-1} in the soils. Organic carbon content was significantly influenced by the management treatments, and ranged from 4.3 to 6.1 g kg^{-1} across the treatments. Among the main treatments, low tillage along with one hand weeding + one weedicide spray and hoeing recorded the highest organic carbon content of 5.6 g kg^{-1} followed by conventional tillage + two weedicides and one hoeing (5.0 g kg^{-1}). Among the conjunctive nutrient use treatments, 100% organic treatments recorded the highest organic carbon content of 5.66 g kg^{-1} followed by 50% inorganic + 50 % organic (5.0 g kg^{-1}), which was at par with that of 100% sole inorganic treatment (5.0 g kg^{-1}). Of all the treatments, LT+ herbicide + 1 weedicide + Hoeing+ 100% organic N recorded the highest organic carbon content of 5.9 g kg^{-1} which was at par with CT+ 2 weedicide + Hoeing+ 100% organic N (5.8 g kg^{-1}).

Nutrient management treatments did not influence the available N content significantly. However available N content in the soil varied from 96.0 to 121.1 kg ha^{-1} across the treatments. Among the tillage practices, irrespective of the nutrient management treatments, LT + 2 weedicides + hoeing recorded the highest available N content of 115.42 kg ha^{-1} which was at par with LT+ herbicide + 1 weedicide + Hoeing (110.3 kg ha^{-1}). Within the interaction effect of tillage and nutrient management treatments, LT+ 2 weedicide + Hoeing+ 100% inorganic N recorded the highest available nitrogen content of 121.1 kg ha^{-1} which was at par with LT + herbicide + 1 weedicide + Hoeing+ 100% organic N (115.7 kg ha^{-1}) and LT+ 2 weedicide + Hoeing+ 50% inorganic N + 50% organic N (115.5 kg ha^{-1}). Available P in the soil was significantly influenced by nutrient management treatment and varied from 38.5 to 56.5 kg ha^{-1} across the treatments. However, tillage alone did not influence the P content. The interaction effects of tillage and conjunctive nutrient use treatments revealed that, CT+ 2 weedicide + Hoeing+ 100% organic N had the highest available phosphorus content of 56.5 kg ha^{-1} followed by CT + 2 weedicide + Hoeing + 50% inorganic N + 50% organic N (50.4 kg ha^{-1}).

Available potassium content in soil was significantly influenced by both tillage and nutrient management treatments. Available K status in these soils varied from 306.5 to 404.2 kg ha^{-1} across the treatments. Among the tillages, LT + herbicide + 1 weedicide + Hoeing recorded significantly highest available K content of 342.6 kg ha^{-1} which was followed by other two tillage practices. Among the conjunctive nutrient use treatments, application of 100% inorganic N recorded significantly highest available K of 342.2 kg ha^{-1} followed by 50% inorganic N + 50% organic N kg ha^{-1} (317.6 kg ha^{-1}). While studying the interaction effects of tillage and conjunctive nutrient use, LT + herbicide + 1 weedicide + Hoeing + 100% inorganic N recorded significantly highest potassium content of 404.2 kg ha^{-1} followed by LT+ herbicide + 1 weedicide + Hoeing+ 50% inorganic N + 50% organic N (348.9 kg ha^{-1}).

Exchangeable Ca was not significantly influenced by any of the management treatments, while exchangeable Mg was significantly influenced. However, exchangeable Ca and Mg in the soil ranged between 8.93 to 10.84 cmol kg^{-1} and 1.45 to 2.76 cmol kg^{-1} of soil across the treatments respectively. Among the tillage practices, LT + herbicide + 1 weedicide + Hoeing recorded significantly highest exchangeable Mg content of 2.26 cmol kg^{-1} followed by LT + 2 weedicide + Hoeing (1.89 c mol kg^{-1}). Among the nutrient use treatments, 100% inorganic N recorded significantly highest exchangeable Mg content of 2.13 cmol kg^{-1}. Among the interaction effects of tillage and nutrient use treatments, LT + herbicide + 1 weedicide + Hoeing+ 100% organic N recorded the highest exchangeable magnesium content of 2.76 cmol kg^{-1} which was at par with LT + herbicide + 1 weedicide + Hoeing+ 100% inorganic N (2.49 c mol kg^{-1}). Available S was significantly influenced by the nutrient management treatments but not tillage and varied from 24.8 to 35.3 kg ha^{-1} across the management treatments. Among the nutrient management treatments, application of nutrients through 100% inorganic sources recorded significantly highest available S (31.9 kg ha^{-1}) followed by the other two practices.

The tillage practices did not show any significant influence on most of the micronutrients viz., Zn Fe, Cu and B, while the nutrient use treatments significantly influenced only the available Zn and B contents of the soils. However, the interactive effects were not significant. Among the nutrient use treatments, application of 100 % inorganic fertilizer recorded significantly highest available Fe content of 6.3 μg g^{-1}, while 50 % inorganic + 50 % organic fertilizer recorded significantly highest copper content of 3.3 μg g^{-1} of soil.

Table 104: Effect of different tillage and soil-nutrient management treatments on soil chemical characteristics under maize-blackgram system in Inceptisols of Arjia.

SNo	Treatments	pH	EC (dS m-1)	OC (g kg-1)	N	P	K
					Kg ha^{-1}		
1	CT + 2 weedicide + hoeing + 100% inorganic N	7.20	0.18	4.34	113.0	38.5	307.0
2	CT + 2 weedicide + hoeing + 100% organic N	7.29	0.21	5.85	96.0	56.5	311.0
3	CT + 2 weedicide + hoeing + 50% inorganic N + 50% organic N	7.27	0.18	4.92	110.8	50.4	297.4
4	LT + herbicide + 1 weedicide + hoeing + 100% inorganic N	7.36	0.22	0.07	106.5	48.9	404.2
5	LT + herbicide + 1 weedicide + hoeing + 100% organic N	7.45	0.23	5.88	115.7	50.1	274.6
6	LT + herbicide + 1 weedicide + hoeing + 50% inorganic N + 50% organic N	7.41	0.25	4.93	108.8	39.7	348.9
7	LT + 2 weedicide + hoeing + 100% inorganic N	7.19	0.19	4.39	121.1	41.0	315.4
8	LT + 2 weedicide + hoeing + 100% organic N	7.51	0.26	4.98	109.6	47.7	295.0
9	LT + 2 weedicide + hoeing + 50% inorganic N + 50% organic N	7.45	0.23	5.10	115.5	42.5	306.5
	CD @0.05						
	Between tillage means	0.03	0.03	0.6	5.4	NS	16.4
	Between treatment means	NS	NS	0.4	NS	3.9	21.8
	Between two treatment means at same tillage	NS	NS	0.6	12.5	6.8	37.7
	Between two treatment means at same or different treatments	NS	NS	0.7	11.1	7.2	33.4

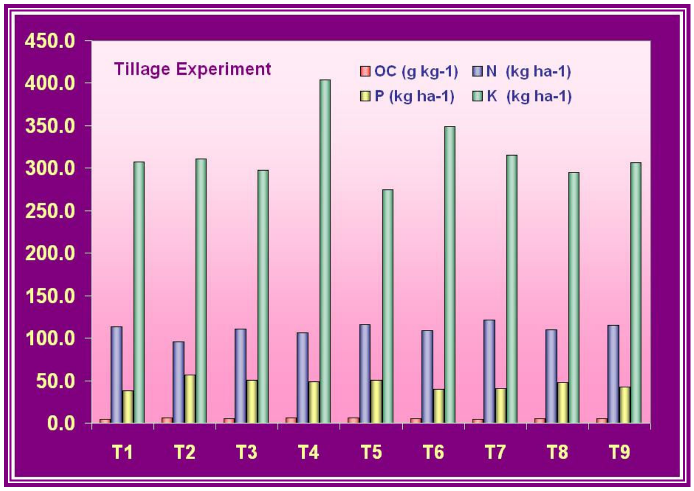


Fig 85: Effect of different tillage and soil-nutrient management treatments on chemical soil quality characteristics (macronutrients) under maize-blackgram system in Inceptisol soils of Arjia.

Table 105: Effect of different tillage and soil-nutrient management treatments on soil secondary and micronutrients under Maize-Blackgram system in Inceptisols of Arjia

SNo	Treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		(c mol kg^{-1})		(kg ha^{-1})	µg g^{-1}				
1	CT + 2 weedicide + hoeing + 100% inorganic N	9.17	1.82	24.8	1.38	6.14	2.76	13.3	0.66
2	CT + 2 weedicide + hoeing + 100% organic N	9.27	1.63	29.1	1.90	5.82	3.44	12.2	0.76
3	CT + 2 weedicide + hoeing + 50% inorganic N + 50% organic N	9.73	1.45	27.9	1.61	5.60	3.26	16.5	0.98
4	LT + herbicide + 1 weedicide + hoeing + 100% inorganic N	9.75	2.49	30.2	1.59	6.65	2.99	17.4	0.95
5	LT + herbicide + 1 weedicide + hoeing + 100% organic N	8.98	2.76	31.4	1.63	5.68	2.97	17.9	0.92
6	LT + herbicide + 1 weedicide + hoeing + 50% inorganic N + 50% organic N	10.8	1.54	27.3	1.84	6.07	3.26	17.2	0.87
7	LT + 2 weedicide + hoeing + 100% inorganic N	9.43	2.07	27.0	1.84	6.04	2.42	14.5	0.87
8	LT + 2 weedicide + hoeing + 100% organic N	9.55	1.45	35.3	1.62	5.29	3.18	16.3	0.82
9	LT + 2 weedicide + hoeing + 50% inorganic N + 50% organic N	8.93	2.14	28.4	1.89	5.39	3.41	13.9	0.97
	CD @0.05								
	Between tillage means	NS	0.21	1.27	NS	NS	NS	2.39	NS
	Between treatment means	NS	0.24	1.21	NS	0.57	0.26	NS	NS

Between two treatment means at same tillage	NS	0.42	2.09	0.32	NS	NS	2.40	NS
Between two treatment means at same or different treatments	NS	0.38	1.98	0.31	NS	NS	2.71	NS

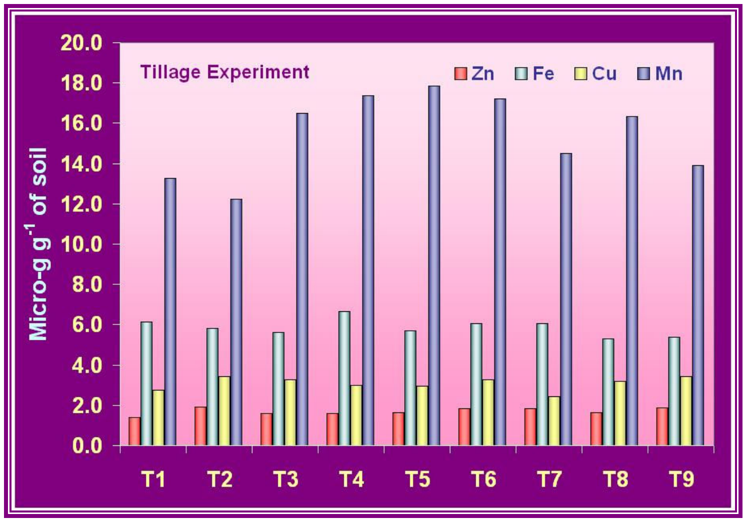


Fig 86: Effect of different tillage and soil-nutrient management treatments on soil micronutrients under Maize-Blackgram system in Inceptisol soils of Arjia

Among the biological parameters, dehydrogenase activity ranged from 1.48 to 1.93 µg TPF $hr^{-1}g^{-1}$ across the treatments. Only tillage treatments showed a significant influence on the dehydrogenase activity. Among the tillage treatments, LT + 2 weedicide + Hoeing recorded the highest dehydrogenase activity of 1.83 µg TPF $hr^{-1}g^{-1}$ which was at par with that of LT + herbicide + 1 weedicide + Hoeing (1.83 µg TPF hr^{-1} g^{-1}). Nutrient management treatments and their interaction effects did not influence dehydrogenase activity significantly. Tillage had no significant influence on the microbial biomass carbon in soil, while the nutrient management treatments showed a significant influence on the microbial biomass activity. Among all the nutrient management treatments, irrespective of the tillage practices, application of 100% organic fertilizer (compost) recorded the highest microbial biomass carbon of 119.7 µg g^{-1} soil, which was at par with that of other two treatments. The interaction effects of tillage and nutrient management treatments also did not show any significant influence on the microbial biomass content of the soils. Labile carbon in the soils ranged from 304.5 to 362.7 mg kg^{-1} across the treatments.

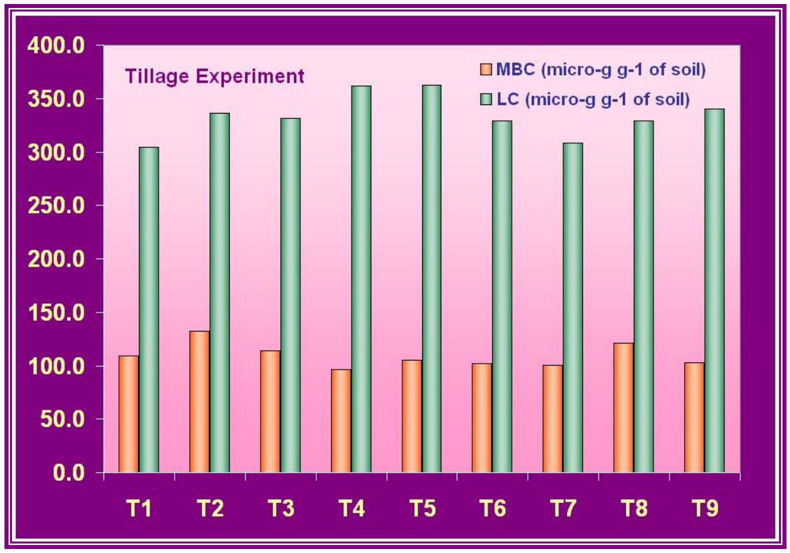


Fig 87: Effect of different tillage and soil-nutrient management treatments on soil biological parameters under Maize-Blackgram system in Inceptisols of Arjia

Tillage practices showed a significant influence on the labile carbon content of the soils where LT+ herbicide + 1 weedicide + Hoeing recorded the highest labile carbon content of 351.2 mg kg^{-1} followed by LT + 2 weedicide + Hoeing (325.8 mg kg^{-1}) which was at par with that of CT + 2 weedicide + Hoeing (323.9 mg kg^{-1}). Among the treatments, irrespective of the tillage, application of 100% organic fertilizer (compost) recorded the highest labile carbon content of 342.5 mg kg^{-1} which was at par with that of 50% inorganic + 50% organic fertilizer application (333.6 mg kg^{-1}). Among the interaction effects of tillage and nutrient use treatments, LT + herbicide + 1 weedicide + Hoeing + 100% organic N recorded the highest labile carbon content of 362.7 mg kg^{-1} which was at par with LT + herbicide + 1 weedicide + Hoeing + 100% inorganic N (361.6 mg kg^{-1}). Tillage, soil-nutrient management treatments and their interactive effects did not show any significant influence on physical soil quality indicators such as bulk density and mean weight diameter of the aggregates studied. However, bulk density and mean weight diameter of aggregates in the soils ranged from 1.26 to 1.35 Mg m^{-3} and 0.17 to 0.25 mm across the treatments respectively.

Table 106: Effect of different tillage and soil-nutrient management treatments on soil physical and biological parameters under Maize-Blackgram system in Inceptisols of Arjia

SNo	Treatments	DHA	MBC	LC	BD	MWD
1	CT + 2 weedicide + hoeing + 100% inorganic N	1.48	109.3	304.5	1.29	0.17
2	CT + 2 weedicide + hoeing + 100% organic N	1.58	132.1	336.0	1.27	0.19
3	CT + 2 weedicide + hoeing + 50% inorganic N + 50% organic N	1.62	113.7	331.4	1.26	0.21
4	LT + herbicide + 1 weedicide + hoeing + 100% inorganic N	1.93	96.3	361.6	1.35	0.20
5	LT + herbicide + 1 weedicide + hoeing + 100% organic N	1.95	105.4	362.7	1.30	0.25
6	LT + herbicide + 1 weedicide + hoeing + 50% inorganic N + 50% organic N	1.60	102.1	329.3	1.29	0.21
7	LT + 2 weedicide + hoeing + 100% inorganic N	1.81	100.6	308.4	1.32	0.17
8	LT + 2 weedicide + hoeing + 100% organic N	1.93	121.4	328.9	1.33	0.19
9	LT + 2 weedicide + hoeing + 50% inorganic N + 50% organic N	1.76	102.8	339.9	1.33	0.20
	CD @0.05					
	Between tillage means	0.15	NS	17.1	NS	NS
	Between treatment means	NS	14.4	13.4	NS	NS
	Between two treatment means at same tillage	NS	NS	23.1	NS	NS
	Between two treatment means at same or different treatments	NS	NS	23.1	NS	NS

4.2.25.1. Key indicators and soil quality assessment

4.2.25.2. Results of principal component analysis

Data pertaining to the influence of different tillage and soil-nutrient management treatments under Maize-Blackgram system in Inceptisols of Arjia on 19 soil quality indices has been statistically analyzed and it was observed that out of 19 soil quality parameters, only four variables viz., exchangeable Ca, available B, bulk density and mean weight diameter were insignificant and hence were dropped from further PCA analysis. In the PCA of 15 variables, five PCs had eigen values >1 and explained 75.0% variance in the data set (Table 107). In PC1, organic carbon and labile carbon were the highly weighted variables. In PC2, PC3 and PC4 only single variables viz., available Fe, available N and available Zn were highly weighted respectively. Again in PC5, two variables viz pH and available Zn were highly weighted. The correlation analysis run between the variables qualified under PC1 and PC5 respectively (Table 108) revealed a significant correlation between the highly weighted variables under PC1 i.e. OC and LC, but depending upon their importance, both were retained for the final MDS, while the variables qualified under PC5 had no significant correlation and hence both were retained. Anyhow, the single variables qualified under PC2, PC3 and PC4 had to be retained for the final MDS. Hence, the final MDS included soil pH, organic carbon, available N, available Zn, available Fe, and labile carbon and were termed the key indicators for different tillage and soil-nutrient management treatments under Maize-Blackgram system in Inceptisols of Arjia.

Table 107: Principal component analysis of soil quality parameters as influenced by different tillage and soil-nutrient management treatments under Maize-Blackgram system in Inceptisols of Arjia

	PC1	PC2	PC3	PC4	PC5
Total Eigen values	3.964	2.491	2.407	1.323	1.58
% of Variance	26.428	16.605	16.047	8.822	7.051
Cumulative %	26.428	43.033	59.080	67.902	74.953
Eigen Vectors					
pH	0.636	-0.304	0.383	-0.073	**0.434**
EC	0.677	-0.222	0.075	0.037	0.264
OC	**0.820**	0.175	-0.323	0.066	-0.190
N	-0.185	-0.013	**0.848**	-0.180	-0.007
P	0.543	-0.188	-0.509	-0.306	-0.317
K	0.128	0.651	-0.213	0.482	0.129
Mg	0.414	0.657	0.165	-0.218	-0.312
S	0.538	-0.223	0.048	-0.118	-0.234
Zn	0.121	-0.410	0.119	**0.683**	**-0.424**
Fe	-0.029	**0.824**	-0.358	0.039	0.242
Cu	0.415	-0.526	-0.318	0.335	-.374
Mn	0.490	0.390	0.295	-0.015	0.287
DHA	0.638	0.058	0.562	-0.189	-0.094
MBC	0.019	-0.273	-0.670	-0.512	0.137
LC	**0.887**	0.151	-0.051	0.124	-0.080

Table 108: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs	OC	LC
PC 1		
OC	1.00	0.776**
LC	0.776**	1.00
Correlation sum	**1.776**	**1.776**
PC 2	pH	Zn
pH	1.00	0.054
Zn	0.054	1.00
Correlation Sum	**1.054**	**1.054**

**correlation is significant at P = 0.01 level

4.2.25.3. Soil quality indices

Soil quality indices were computed using six key soil quality indicators viz., soil pH, organic carbon, available N, available Zn, available Fe, and labile carbon. The soil quality indices varied from 1.62 to 1.89 across the tillage and nutrient management treatments (Table 109). The soil quality indices, when reduced to a scale of one, termed as 'relative soil quality indices' (RSQI) varied between 0.84 to 0.98 (Fig 88). From the data, it was observed that tillage showed a significant influence while the nutrient management treatments did not show any significant influence in maintaining soil quality while their interaction effects had a significant influence. Among the tillage methods, practice of low tillage + herbicide + 1 weedicide + hoeing maintained significantly highest SQI of 1.84 followed by the other two methods. Of all the treatments, practice of LT + herbicide + 1 weedicide + hoeing + 100% inorganic N maintained significantly highest SQI of 1.89 which was at par with LT + herbicide + 1 weedicide + hoeing + 100% organic N (1.87). The average percent contribution of key indicators towards soil quality indices was: soil pH (8%), organic carbon (24%), available N (16%), available Zn (8%), available Fe (16%), and labile carbon (28%) (Fig 89).

Table 109: Effect of tillage and soil-nutrient management treatments on soil quality indices and relative soil quality indices under maize-blackgram system at Arjia (Rajasthan)

SNo	Treatments	SQI	RSQI
1	T1: CT + 2 weedicide + hoeing + 100% inorganic N	1.62	0.84
2	T2: CT + 2 weedicide + hoeing + 100% organic N	1.78	0.93
3	T3: CT + 2 weedicide + hoeing + 50% inorganic N + 50% organic N	1.72	0.89
4	T4: LT + herbicide + 1 weedicide + hoeing + 100% inorganic N	1.89	0.98
5	T5: LT + herbicide + 1 weedicide + hoeing + 100% organic N	1.87	0.97
6	T6: LT + herbicide + 1 weedicide + hoeing + 50% inorganic N + 50% organic N	1.74	0.90
7	T7: LT + 2 weedicide + hoeing + 100% inorganic N	1.67	0.87
8	T8: LT + 2 weedicide + hoeing + 100% organic N	1.71	0.89
9	T9: LT + 2 weedicide + hoeing + 50% inorganic N + 50% organic N	1.77	0.92
	CD @0.05		
	Between tillage means	0.04	0.02
	Between treatment means	NS	NS
	Between two treatment means at same tillage	0.11	0.06
	Between two treatment means at same or different treatments	0.09	0.05

Fig 88: Effect of tillage and soil-nutrient management treatments on soil quality indices under maize-blackgram system at Arjia (Rajasthan)

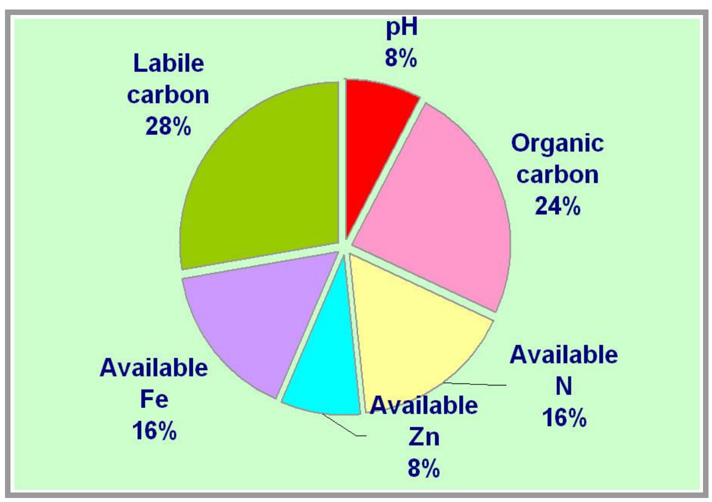


Fig 89: Percent contributions of key indicators towards soil quality indices as influenced by tillage and soil-nutrient management treatments under maize-blackgram system at Arjia (Rajasthan)

4.2.26. Experiment 2: Integrated nutrient supply system for rainfed semiarid tropics under maize, blackgram strip and block system

This experiment was initiated during 1998 and test crops were maize (cv. Navjot) and blackgram (T-9). Recommended dose of fertilizer for maize was 50 kg N and 30 kg P_2O_5 ha^{-1}. For legume block, 30 kg P_2O_5 ha^{-1} was applied which was rotated with cereal block. In strip cropping, cereal and legume were rotated every year. In this way, three systems viz., i) maize-black gram strip system, ii) block system maize and iii) block system blackgram were evaluated for soil quality and soil quality indices.

In the present study, the composite soil samples received in triplicate from above blocks from Arjia centre were evaluated for 19 physical, chemical and biological soil quality indicators. The data on soil quality indicators are presented in Tables 110 to 112 & Fig 90 to 93.

Soils of the experimental field were found to be almost neutral in reaction tending towards slight salinity with pH of 7.25 to 7.32. Electrical conductivity of the soils ranged from 0.18 to 0.22 dS m^{-1} and organic carbon 3.9 to 4.7 g kg^{-1}. It was clearly observed that the macronutrient content i.e., available N, P and K content of the soils were not significantly influenced by the type of cropping systems. However, available nitrogen in these systems ranged from 123.2 to 127.8 kg ha^{-1}, available phosphorus form 19.2 to 33.8 kg ha^{-1} and available potassium from 321.4 to 364.3 kg ha^{-1}. Exchangeable calcium in the soils was significantly influenced by the cropping systems and ranged from 7.8 to 16.8 cmol kg^{-1}. Among the systems, strip system of maize and black gram recorded the highest exchangeable calcium (16.8 kg cmol kg^{-1}) while blocks of black gram recorded the lowest (7.8 kg ha^{-1}). Exchangeable magnesium was also not significantly influenced by the management treatments. Available sulphur in these soils was significantly influenced by the cropping system and was found to be highest under strip system of maize-blackgram (10.88 kg ha^{-1}), while it was lowest under black gram block system (7.92 kg ha^{-1}).

Table 110: Soil parameters as influenced by different blocks /strips under Maize-Blackgram in Inceptisols of Arjia - Physico-chemical and macronutrients

Sno	Name of the treatments	pH	EC dS m^{-1}	OC (g kg^{-1})	N	P	K	Ca	Mg	S kg ha^{-1}
					(kg ha^{-1})			cmol kg^{-1}		
1	Strip system-Maize-Blackgram	7.32	0.18	3.9	127.8	19.2	364.3	16.8	2.4	10.88
2	Block Systems-Maize	7.25	0.18	4.4	123.6	32.4	321.4	8.4	2.1	8.09
3	Block system- Black gram	7.25	0.22	4.7	123.2	33.8	355.5	7.8	2.6	7.92
	CD @ 0.05	NS	NS	NS	NS	NS	NS	2.96	NS	2.23

Table 111: Soil parameters as influenced by different blocks /strips under Maize-Blackgram in Inceptisols of Arjia.- micronutrients

Sno	Name of the treatments	Zn	Fe	Cu	Mn	B
		μg g^{-1}				
1	Strip system-Maize-Blackgram	1.78	7.41	2.7	13.65	0.72
2	Block Systems-Maize	1.67	6.68	2.6	12.06	0.77
3	Block system- Black gram	1.59	7.76	3.5	6.59	0.80
	CD @ 0.05	NS	NS	NS	4.52	NS

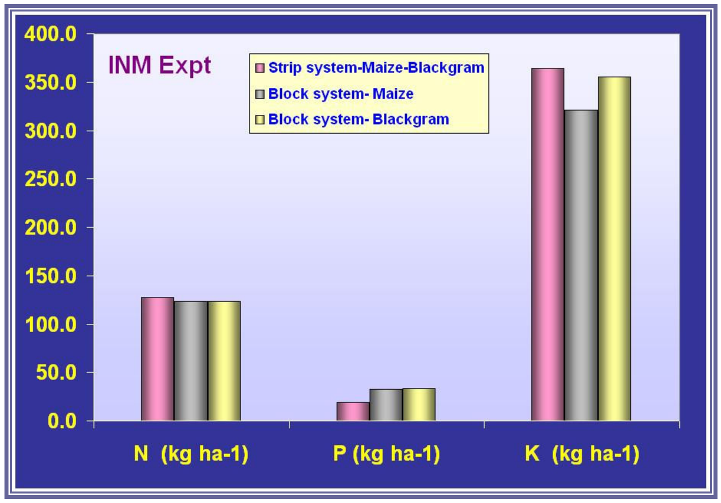


Fig 90: Soil parameters as influenced by different blocks /strips under Maize-Blackgram in Inceptisols of Arjia - Macronutrients

The cropping systems did not show any significant influence on the DTPA extractable micronutrients except Mn. However, Zn, Fe, Cu and B in these soils ranged from 1.59 to 1.78, 6.68 to 7.76, 2.6 to 3.5 and 0.72 to 0.80 μg g^{-1} of soil respectively. Strip system of maize-blackgram recorded significantly highest available Mn (13.65 μg g^{-1} of soil) while, blocks system of black gram recorded the lowest amount (6.59 μg g^{-1} of soil).

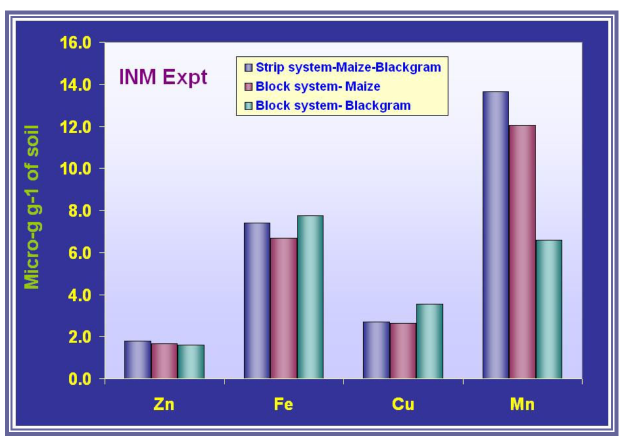


Fig 91: Soil parameters as influenced by different blocks /strips under Maize-Blackgram in Inceptisols of Arjia - Micronutrients

There was no significant influence of crop blocks under maize-blackgram system on physical and biological soil quality parameters. However, dehydrogenase activity in the soil ranged from 1.19 to 2.09 μg TPF $hr^{-1}g^{-1}$, microbial biomass carbon from 108.4 to 115.7 μg g^{-1} of soil and labile carbon

291.0 to 303.8 μg g^{-1} of soil. The bulk density in the systems varied from 1.26 to 1.32 Mg m^{-3} while the mean weight diameter varied from 0.13 to 0.19 mm.

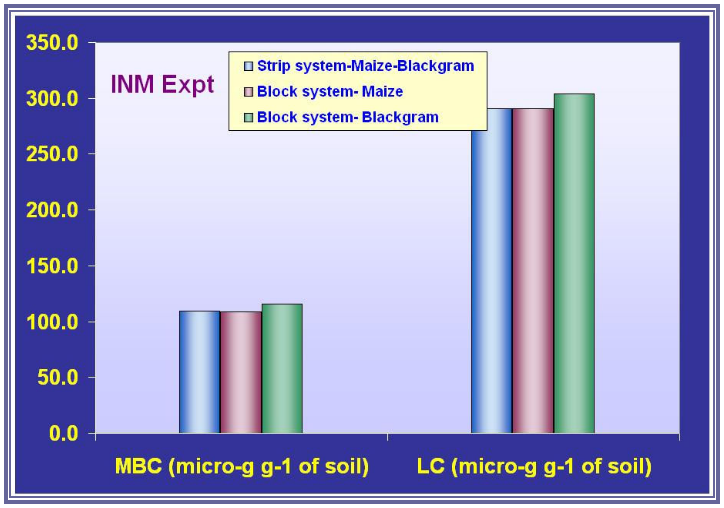


Fig 92: Soil parameter as influenced by different blocks / strips under Maize-Blackgram in Inceptisols of Arjia - Biological parameters

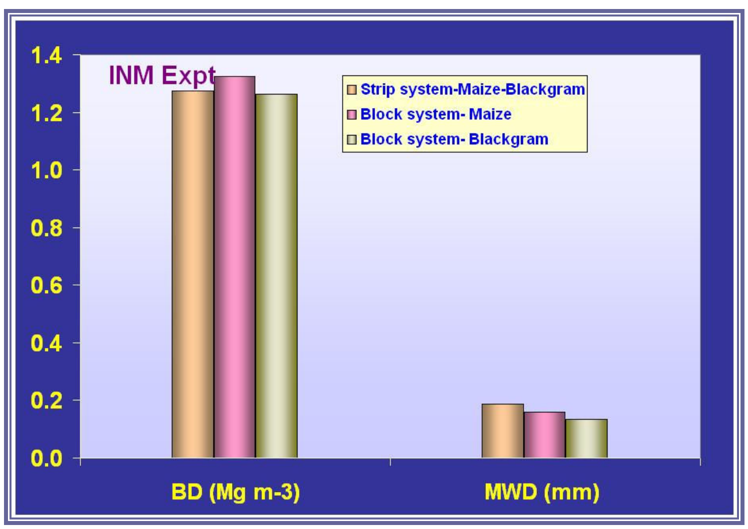


Fig 93: Soil parameters as influenced by different blocks / strips under Maize-Blackgram in Inceptisols of Arjia - Physical parameters

Table 112: Soil parameter as influenced by different blocks / strips under Maize-Blackgram in Inceptisols of Arjia - Physical and biological parameters

Sno	Name of the treatments	Dehydrogenase assay (μg TPF $hr^{-1}g^{-1}$)	Microbial biomass carbon (μg g^{-1} of soil)	Labile carbon (μg g^{-1} of soil)	Bulk density (Mg m^{-3})	MWD (mm)
1	Strip system-Maize-Blackgram	1.19	109.5	291.0	1.27	0.19
2	Block Systems-Maize	1.84	108.4	290.8	1.32	0.16
3	Block system- Black gram	2.09	115.7	303.8	1.26	0.13
	CD @ 5%	NS	NS	NS	NS	NS

4.2.26.1. Computation of soil quality indices

As most of the soil quality parameters were not significantly influenced by the management treatments, soil quality assessment using principal component analysis was not done and soil quality indices could not be computed.

4.2.27. Experiment 3: Farmers Fields

In addition to experimental station, soil quality assessment was also taken up in farmer's field at Arjia. To achieve this, soil samples collected form farmers field representing predominant cropping system such as Maize-Blackgram, Groundnut- Sesame and Groundnut-Taramira with farmers management levels were analyzed for 19 soil quality indicators. The data on soil quality indicators have been presented in Tables 113 to 115 & Fig 94 to 96.

Soil reaction was found to be neutral to slightly alkaline and pH ranged from 7.23 to 7.35 across the systems. Cropping systems did not show any significant differences in the soil reaction. Electrical conductivity in the farmer's fields ranged between 0.25 to 0.36 dS m^{-1}. Among all the systems, groundnut-taramira systems showed significantly highest electrical conductivity (0.36 dS m^{-1}), compared to others. Groundnut-sesame system recorded significantly highest organic carbon content of 7.3 g kg^{-1}, while the lowest organic carbon (4.3 g kg^{-1}) was observed in groundnut-taramira system. There was no effect of cropping systems studied under farmer's situation on available nitrogen content in soil. However, N content ranged from 103 to 107 kg ha^{-1} across the system. Available phosphorus and potassium were significantly influenced under different cropping systems, where groundnut-taramira system showed significantly highest available phosphorus content of 15.38 kg ha^{-1}, while, the lowest amount was recorded under maize-blackgram system (4.3 kg ha^{-1}). While in case of available potassium, a reverse trend was observed where maize-blackgram system recorded significantly highest available potassium content of 260.2 kg ha^{-1} while groundnut-taramira system recorded the lowest amount (177.9 kg ha^{-1}).

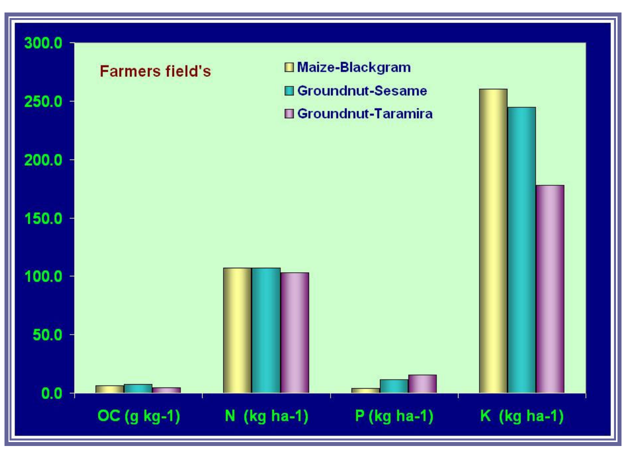


Fig 94: Soil parameters as influenced by different cropping systems in farmer's fields of Arjia. – Physico-chemical and macronutrients

Exchangeable calcium was found significantly highest under groundnut-sesame system (14.59 cmol kg^{-1}) while exchangeable magnesium was found to be significantly highest under groundnut-taramira system (3.64 cmol kg^{-1}). Available sulphur in these cropping systems varied between 12.91 kg ha^{-1} under maize black gram system and 14.37 kg ha^{-1} under groundnut-taramira system.

Among the micronutrients analyzed in farmer's fields under different cropping systems, DTPA extractable Fe and Cu were found to be significantly influenced by the systems while Zn, Mn and B were not influenced. However, Zn, Mn and B ranged between 1.49 to 1.76, 23.12 to 26.59 and 0.72 to 0.94 μg g^{-1} of soil across the systems. Available Mn content recorded was found considerably high and needs reconfirmation. Available Fe was significantly higher in maize-blackgram system (13.71μg g^{-1} of soil), while it was lowest under groundnut –taramira system (2.19 μg g^{-1} of soil). Similarly, available Cu content was found to be significantly higher under groundnut-sesame system (3.70 μg g^{-1} of soil), while it was lowest under groundnut-taramira system (2.77 μg g^{-1} of soil).

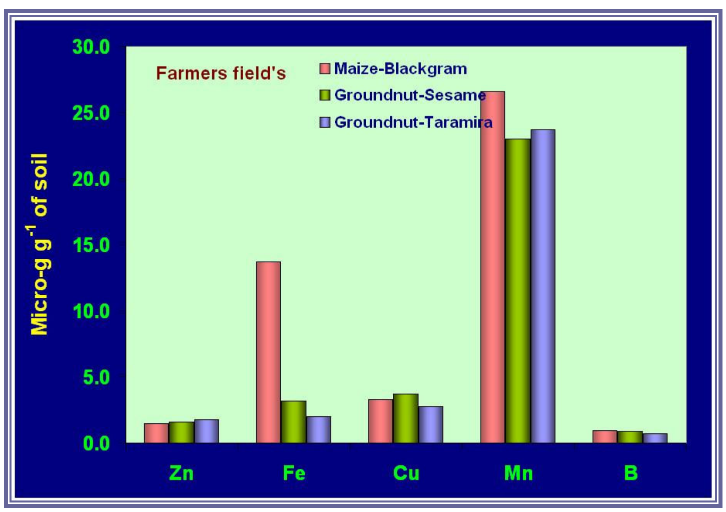


Fig 95: Soil parameters as influenced by different cropping systems in farmers fields of Arjia. – Micronutrients

Most of the biological soil quality parameters studied under farmer's fields was significantly influenced by the cropping systems. Among the cropping systems, groundnut –taramira systems recorded significantly higher dehydrogenase activity of 1.67 μg TPF g^{-1} hr^{-1} while microbial biomass carbon (79.25 μg g^{-1} soil) and labile carbon (117.28 μg g^{-1} soil) were found to be lowest in this system. Among the physical soil quality parameters, bulk density was significantly influenced by different cropping systems, while mean weight diameter of soil aggregates was not much affected. Among the cropping systems, groundnut-sesame recorded significantly lower bulk density of 1.11 Mg m^{-3} while ground –taramira recorded the highest (1.39 Mg m^{-3}).

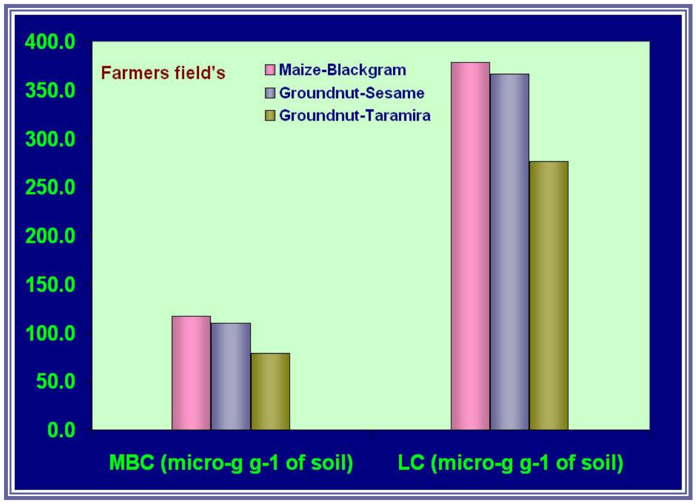


Fig 96: Soil biological parameters as influenced by different cropping systems in farmers fields of Arjia

Undisturbed site at Arjia

Soil sample from an undisturbed site of Arjia were also analyzed and various soil quality characteristics are given in Table 116.

Table 113: Soil parameters as influenced by different cropping systems in farmer's fields of Arjia. – Physico-chemical and macronutrients

Sno	Name of the treatments	pH	EC dS m^{-1}	OC (g kg^{-1})	N	P	K	Ca	Mg	S
					(kg ha^{-1})			cmol kg^{-1}		kg ha^{-1}
1	Maize-Blackgram	7.23	0.25	6.5	107.1	4.30	260.2	12.51	2.70	12.91
2	Groundnut- Sesame	7.35	0.26	7.3	107.3	11.34	244.8	14.59	3.45	13.59
3	Groundnut-Taramira	7.25	0.36	4.3	103.0	15.38	177.9	6.08	3.64	14.37
	CD @ 0.05	NS	0.08	1.41	NS	3.75	44.3	2.8	0.43	NS

Table 114: Soil parameters as influenced by different cropping systems in farmer's fields of Arjia. – Micronutrients

Sno	Name of the treatments	Zn	Fe	Cu	Mn	B
				$\mu g\ g^{-1}$		
1	Maize-Blackgram	1.49	13.71	3.28	26.59	0.94
2	Groundnut- Sesame	1.57	3.17	3.70	23.12	0.86
3	Groundnut- Taramira	1.76	2.19	2.77	23.70	0.72
	CD @ 0.05	NS	2.21	0.56	NS	NS

Table 115: Soil parameters as influenced by different cropping systems in farmer's fields of Arjia. – Physical and biological

Sno	Name of the treatments	Dehydrogenase assay (μg TPF $hr^{-1}g^{-1}$)	Microbial biomass carbon ($\mu g\ g^{-1}$ of soil)	Labile carbon ($\mu g\ g^{-1}$)	Bulk density ($Mg\ m^{-3}$)	MWD (mm)
1	Maize-Blackgram	0.62	117.28	378.2	1.16	0.26
2	Groundnut- Sesame	0.82	109.77	366.7	1.11	0.32
3	Groundnut- Taramira	1.67	79.25	276.4	1.39	0.31
	CD @ 5%	0.45	17.98	31.33	0.10	NS

Table 116: Soil quality characteristics of an undisturbed sample of Arjia centre

pH	EC (dSm^{-1})	OC ($g\ kg^{-1}$)	N ($kg\ ha^{-1}$)	P ($kg\ ha^{-1}$)	K ($kg\ ha^{-1}$)	Ca ($cmol\ kg^{-1}$)
7.77	0.23	4.5	82.37	2.60	157.1	13.73
Mg ($cmol\ kg^{-1}$)	S ($kg\ ha^{-1}$)	Zn ($\mu g\ g^{-1}$)	Fe ($\mu g\ g^{-1}$)	Cu ($\mu g\ g^{-1}$)	Mn ($\mu g\ g^{-1}$)	B ($\mu g\ g^{-1}$)
3.96	41.42	1.59	1.69	2.36	7.52	1.10
DHA (μg TPF $hr^{-1}g^{-1}$)	MBC ($\mu g\ g^{-1}$ of soil)	LC ($\mu g\ g^{-1}$ of soil)	BD ($Mg\ m^{-3}$)	MWD (mm)		
0.33	106.0	253.8	1.24	0.54		

4.2.27.1. Key indicators and soil quality assessment

4.2.27.2. Results of principal component analysis

Data pertaining to the influence of different cropping systems under farmers fields in Inceptisols of Arjia on 19 soil quality indices has been statistically analyzed and it was observed that out of 19 soil quality parameters, seven variables viz., soil pH, available N, available S, available Zn, Mn & B, and mean weight diameter were insignificant and hence were dropped from further PCA analysis. In the PCA of 12 variables, two PCs had eigen values >1 and explained 88.0% variance in the data set (Table 117). In PC1, seven variables viz., electrical conductivity, organic carbon, available K, exchangeable Ca, dehydrogenase assay, labile carbon and bulk density were the highly weighted variables, while in PC2, available Fe is the only variable which has been highly weighted. The correlation analysis run between the variables qualified under PC1 (Table 118) revealed quite significant correlation between all the highly weighted variables under PC1 i.e. OC, available K, exchangeable Ca, DHA, labile carbon and bulk density. However, depending on their importance, except available K, which had the lowest correlation sum (5.862) and electrical conductivity, all the other five out of seven variables were retained for the final MDS. Under PC2, since only available Fe was the only variable highly qualified, it had to be retained for the final MDS. Hence, the final MDS included six soil quality variables viz., organic carbon, exchangeable Ca, available Fe, dehydrogenase assay, labile carbon and bulk density and were termed the key indicators for different cropping systems under farmers fields Inceptisols of Arjia.

Table 117: Principal component analysis of soil quality parameters as influenced by different cropping systems under farmers fields in Inceptisols of Arjia

	PC1	PC2
Total Eigen values	8.831	1.731
% of Variance	73.594	14.428
Cumulative %	73.594	88.022
Eigen Vectors		
EC	**-0.901**	-0.022
OC	**0.884**	0.384
P	-0.831	0.466
K	**0.921**	-0.046
Ca	**0.903**	0.338
Mg	-0.703	0.606
Fe	0.672	**-0.712**
Cu	0.738	0.536
DHA	**-0.937**	0.048
MBC	0.840	0.015

	PC1	PC2
LC	**0.973**	0.039
BD	**-0.929**	-0.290

Table 118: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs	EC	OC	K	Ca	DHA	LC	BD
PC 1							
EC	1.00	-0.835**	-0.817**	-0.872**	0.882**	-0.901**	0.850**
OC	-0.835**	1.00	0.726*	0.897**	-0.799**	0.910**	-0.981**
K	-0.817**	0.726*	1.00	0.838**	-0.824**	0.888**	-0.769*
Ca	-0.872**	0.897**	0.838**	1.00	-0.848**	0.869**	-0.908**
DHA	0.882**	-0.799**	-0.824**	-0.848**	1.00	-0.927**	0.891**
LC	-0.901**	0.910**	0.888**	0.869**	-0.927**	1.00	-0.946**
BD	0.850**	-0.981**	-0.769*	-0.908**	0.891**	-0.946**	1.00
Correlation Sum	6.157	6.148	5.862	6.232	6.171	6.441	6.345

*correlation is significant at P = 0.05 level
**correlation is significant at P = 0.01 level

4.2.27.3. Soil quality indices

Soil quality indices were computed using six key soil quality indicators viz., organic carbon, exchangeable Ca, available Fe, dehydrogenase assay, labile carbon and bulk density. The soil quality indices varied from 2.77 to 3.53 across the various cropping systems under farmers fields (Table 119). The soil quality indices, when reduced to a scale of one, termed as 'relative soil quality indices' (RSQI) varied between 0.76 to 0.98 (Fig 97). From the data, it was observed that among the cropping systems, groundnut-sesame system maintained highest soil quality index (3.53) and was at par with maize-blackgram system (3.38) while groundnut-taramira system maintained the lowest SQI of 2.77. Hence, the relative order of the management treatments in influencing soil quality indices, irrespective of their statistical significance was: Groundnut- Sesame (3.532) > Maize-Blackgram (3.375) > Groundnut- Taramira (2.765). The average percent contribution of key indicators towards soil quality indices was: organic carbon (20%), exchangeable Ca (18%), available Fe 92%), dehydrogenase assay (14%), labile carbon (23%) and bulk density (23%) (Fig 98).

Table 119: Soil quality indices as influenced by cropping systems under farmer's fields in Inceptisols of Arjia.

Sno	Treatments	Soil quality index (SQI)	Relative Soil Quality Index (RSQI)
1	Maize-Blackgram	3.375	0.935
2	Groundnut- Sesame	3.532	0.979
3	Groundnut- Taramira	2.765	0.766
	CD @ 0.05	0.31	0.09

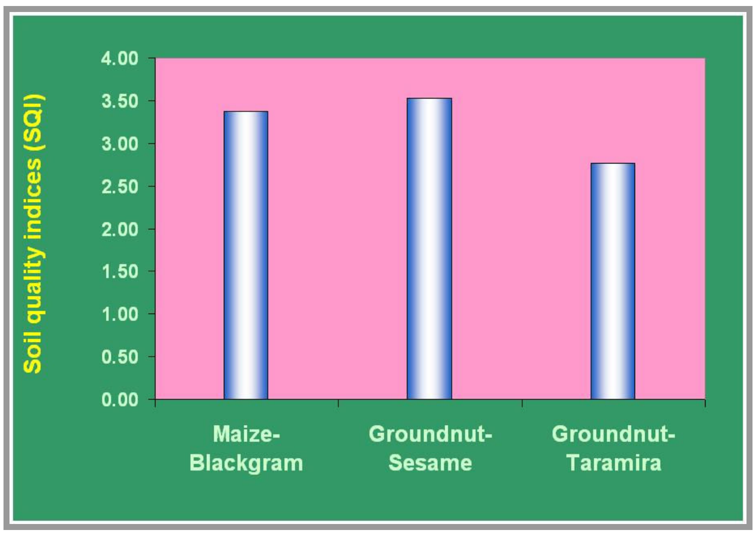


Fig 97: Soil quality indices as influenced by different cropping systems under farmer's field in Inceptisols of Arjia (Rajasthan)

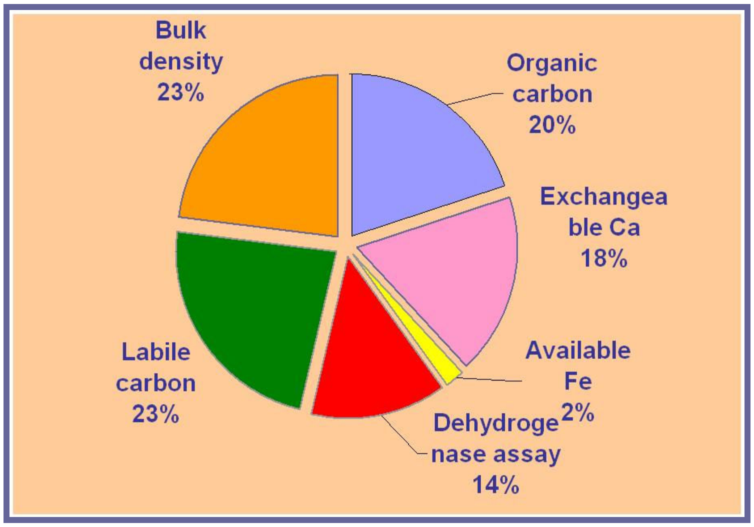


Fig 98: Percent contribution of soil quality indices as influenced by different cropping systems under farmer's field in Inceptisols of Arjia (Rajasthan)

Table 120: Summary of soil quality indices and relative soil quality indices as influenced by different soil nutrient management practices under different trials practiced in Inceptisols of Arjia (Rajasthan)

Sno		SQI	RSQI
Experiment 1: Low till farming strategies for resources conservation and improving soil quality			
1	T1: CT + 2 weedicide + hoeing + 100% inorganic N	1.62	0.84
2	T2: CT + 2 weedicide + hoeing + 100% organic N	1.78	0.93
3	T3: CT + 2 weedicide + hoeing + 50% inorganic N + 50% organic N	1.72	0.89
4	T4: LT + herbicide + 1 weedicide + hoeing + 100% inorganic N	1.89	0.98
5	T5: LT + herbicide + 1 weedicide + hoeing + 100% organic N	1.87	0.97
6	T6: LT + herbicide + 1 weedicide + hoeing + 50% inorganic N + 50% organic N	1.74	0.90
7	T7: LT + 2 weedicide + hoeing + 100% inorganic N	1.67	0.87
8	T8: LT + 2 weedicide + hoeing + 100% organic N	1.71	0.89
9	T9: LT + 2 weedicide + hoeing + 50% inorganic N + 50% organic N	1.77	0.92
Experiment 2: Integrated nutrient supply system for rainfed semiarid tropics under maize, blackgram strip and block system			
	--	--	--
Experiment 3: Farmers fields			
1	Maize- Black gram	3.38	0.94

Sno		SQI	RSQI
2	Ground nut - Sesame	3.53	0.98
3	Groundnut - Taramira	2.77	0.77

Table 121: Summary of key soil quality indicators, soil quality indices and the best soil nutrient management practices identified under different cropping systems in Inceptisols of Arjia (Rajasthan)

Sno	Key soil quality indicators and their % contribution	SQI	RSQI	Best management practices with higher SQI
Experiment 1: Low till farming strategies for resources conservation and improving soil quality				
	• pH (8%) • Organic carbon (24%) • Available N (16%) • Available Zn (8%) • Available Fe (16%) • Labile carbon (28%)	1.62 – 1.89	0.84 – 0.98	1. Practice of low tillage + herbicide + 1 weedicide + hoeing (1.84) 2. LT + herbicide + 1 weedicide + hoeing + 100% inorganic N (1.89) 3. LT + herbicide + 1 weedicide + hoeing + 100% organic N (1.87)
Experiment 2: Integrated nutrient supply system for rainfed semiarid tropics under maize, blackgram strip and block system				
	--	--	--	--
Experiment 3: Farmers fields				
	• Organic carbon (20%) • Exchangeable Ca (18%) • Available Fe (2%) • Dehydrogenase assay (14%) • Labile carbon (23%) • Bulk density (23%)	2.77 – 3.53	0.77 – 0.98	1.Groundnut- Sesame (3.53) 2.Maize-Blackgram (3.38) 3.Groundnut- Taramira (2.77)

Rakhdhiansar Centre

Maize based production system

4.2.28. Effect of predominant soil and nutrient management practices on soil quality indicators (attributes) and soil quality indices at Rakhdhiansar centre of AICRPDA

Location description, climate and soil characteristics

Rakh Dhiansar is in Kandi areas of Western Himalayas of South Kashmir and Kumaon, warm moist to dry sub-humid transitional eco-sub-region (AESR 14.2) and it is at higher elevation than the other centers. The mean annual rainfall is 1180 mm of which 60 percent is received during July-August. Winter rains account for 225 mm. Length of growing period is 150-210 days. The soils are medium to deep loamy to clayey brown forest, podzolic and are medium deep sandy loam to loamy. Soils have medium available water capacity with neutral soil reaction and suitable electrical conductivity. Soils are low in organic carbon, nitrogen and phosphorus and low to medium in potassium. Water erosion occurs with slight loss of topsoil (11-25% area), slight chemical deterioration (6-10% area), slight water logging (6-10% area). The traditional crops/cropping systems in Kharif are maize, pearl millet, cowpea, greengram, blackgram, lentil, pea, mustard etc., in rabi and the sequence croppings are maize-wheat/ mustard/ barley/ toria/ chickpea, blackgram-wheat/ rapeseed etc. Maize and pluses dominate in sequence cropping. The recommendation domain of the centre is Jammu and Kathua districts.

In order to study the effect of predominant soil and nutrient management practices on soil quality indicators, and the soil quality indices, the following four experiments and the farmer's fields were chosen at Rakhdhiansar centre.

- Experiment 1: Integrated nutrient supply system for rainfed semi-arid tropics
- Experiment 2: Permanent manurial trial
- Experiment 3: Nutrient management in maize- wheat rotation
- Experiment 4: Tillage and nutrient management for resource conservation and improving soil quality.
- Experiment 5: Farmers Fields

4.2.29. Experiment 1: Integrated nutrient supply system for rainfed semi arid tropics

The soils generally found in dryland regions of Jammu are inherently poor in nutrient status with low organic matter content and also low water holding capacity. The production and recycling of biomass is also showing decreasing trend thereby affecting the productivity and sustainability of these soils. The aim of the present integrated nutrient management study is to reduce the use of inorganic fertilizers and supplement with nutrient supply through organic source, hence the use of compost is to be encouraged instead of FYM considering its short supply. Moreover, inclusion of organic waste in composting also serves as a means for organic recycling. In order to minimize the dependence on the use of inorganic fertilizers and to build up soil fertility and improve soil health, an experiment was initiated during kharif 1998 in a randomized block design with nine INM treatments in three replications using maize (Kanchan hybrid -510) and black gram (Pant U-19) as test crops. Of the nine INM treatments, six INM treatments viz., T1: Control; T2: 100 % N (inorganic); T3: 50 % N (inorganic); T4: 25 kg N (compost); T5: 15 kg N (compost) + 10 kg N (inorganic) and T6: 15 kg N (compost) + 20 kg N (inorganic) were chosen for the present soil quality assessment study which was conducted during 2005 after eight years of experimentation to assess the influence of these integrated nutrient management treatments on soil quality.

From the data presented in Table 122 it was observed that the soil pH varied from 6.10 to 6.35 across the INM treatments while EC varied from 0.06 to 0.09 dS m^{-1}. Soil organic carbon as influenced by these INM treatments was medium ranging from 3.24 to 5.20 g kg^{-1} and was significantly highest under application of 25 kg N (compost) (5.20 g kg^{-1}) as well as under application of 15 kg N (compost) + 20 kg N (inorganic) (5.19 g kg^{-1}). Among the chemical soil quality parameters, available N and P were significantly influenced by the management treatments while available K was not influenced. Significantly highest available N content of 156.5 kg ha^{-1} was observed under application of 25 kg N through compost which was at par with other treatments while the lowest was observed under control plot (139.2 kg ha^{-1}). Available P in the treated plots was high in these soils and significantly highest available P was recorded under application of 15 kg N (compost) + 20 kg N (inorganic) (36.7 kg ha^{-1}) which was at par with other treatments. Available K, not being conspicuously influenced by the management treatments, varied from 161.7 to 207.1 kg ha^{-1} across the treatments (Fig 99).

Table 122: Effect of different integrated nutrient management treatments on physico-chemical and chemical soil quality parameters under maize-black gram system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	pH	EC dS m^{-1}	OC (g kg^{-1})	N	P	K
					(kg ha^{-1})		
1	T1: Control	6.12	0.08	3.24	139.2	19.5	161.7
2	T2: 100 % N (inorganic)	6.26	0.06	4.65	155.4	31.6	186.2
3	T3: 50 % N (inorganic)	6.20	0.07	4.68	142.2	31.8	192.9
4	T4: 25 kg N (compost)	6.11	0.07	5.20	156.5	32.8	183.9
5	T5: 15 kg N (compost) + 10 kg N (inorganic)	6.35	0.07	4.28	143.0	34.4	204.7
6	T6: 15 kg N (compost) + 20 kg N (inorganic)	6.10	0.09	5.19	147.9	36.7	207.1
	CD @ 0.05	NS	NS	1.01	11.2	7.31	NS

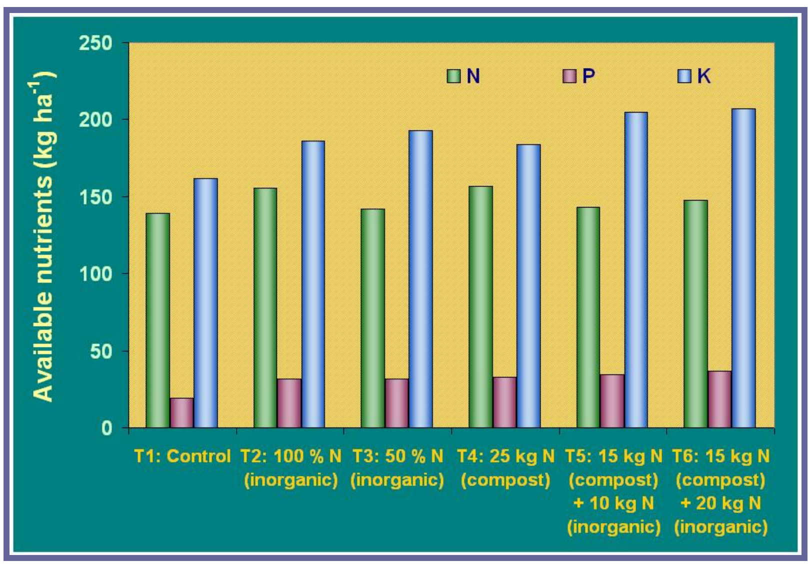


Fig 99: Effect of different integrated nutrient management treatments on chemical soil quality parameters (macronutrients) under maize-black gram system in Inceptisols of Rakhdhiansar

Among the secondary nutrient parameters, both exchangeable Ca and Mg irrespective of their significant influence by the INM treatments, varied from 2.47 to 3.76 cmol kg^{-1} and 0.43 to 0.52 cmol kg^{-1} respectively (Table 123 & Fig 100). However, available S, being significantly influenced by the management treatments was observed to be highest under application of 25 kg N through compost (22.7 kg ha^{-1}) which was at par with other treatments while the lowest was recorded under control plot (13.7 kg ha^{-1}). Among the micronutrient parameters, available Zn and B were conspicuously influenced by the management treatments while Fe, Cu and Mn were not influenced. However, available Zn, Fe and Mn contents were observed to be in high range varying from 0.96 to 2.14, 14.9 to 19.4 and 18.3 to 24.0 µg g^{-1} respectively across the treatments, while available Cu and B were observed to be in medium range varying from 0.76 to 0.91 and 0.28 to 0.51 µg g^{-1} respectively (Fig 101).

Table 123: Effect of different integrated nutrient management treatments on chemical soil quality parameters under maize-black gram system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		cmol kg^{-1}		(kg ha^{-1})	µg g^{-1}				
1	T1: Control	2.47	0.43	13.7	0.96	14.9	0.76	18.3	0.28
2	T2: 100 % N (inorganic)	3.21	0.46	16.4	1.56	18.5	0.89	21.8	0.40
3	T3: 50 % N (inorganic)	3.20	0.49	19.9	1.64	16.4	0.81	24.0	0.40
4	T4: 25 kg N (compost)	3.76	0.49	22.7	2.14	18.3	0.83	21.3	0.51
5	T5: 15 kg N (compost) + 10 kg N (inorganic)	3.12	0.51	21.3	1.80	19.4	0.88	20.9	0.45
6	T6: 15 kg N (compost) + 20 kg N (inorganic)	3.66	0.52	20.2	2.06	18.2	0.91	23.7	0.49
	CD @ 0.05	0.44	NS	5.12	0.44	NS	NS	NS	0.07

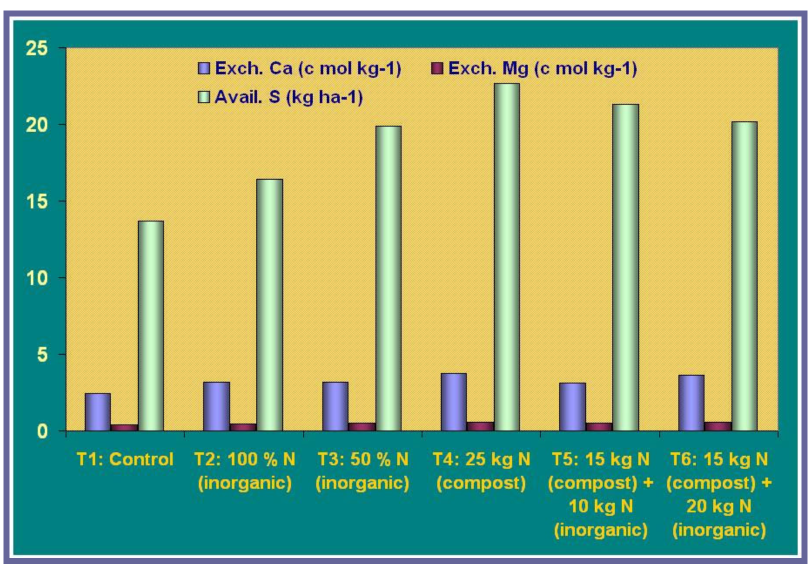


Fig 100: Effect of different integrated nutrient management treatments on chemical soil quality parameters (Secondary nutrients) under maize-black gram system in Inceptisols of Rakhdhiansar

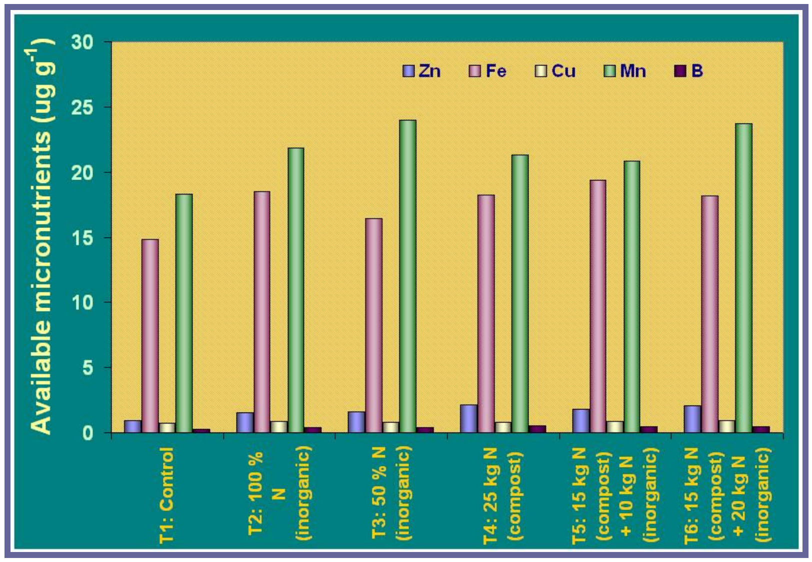


Fig 101: Effect of different integrated nutrient management treatments on chemical soil quality parameters (micronutrients) under maize-black gram system in Inceptisols of Rakhdhiansar

The biological parameters viz., DHA, microbial biomass carbon as well as labile carbon were significantly influenced by the management treatments (Table 124 & Fig 102). Across the management treatments, dehydrogenase assay varied from 1.76 to 2.79 μg TPF $hr^{-1}g^{-1}$, microbial biomass carbon from 102.7 to 162.0 μg g^{-1} of soil and labile carbon from 277.5 to 355.0 μg g^{-1} of soil. Application of 15 kg N (compost) + 20 kg N (inorganic) recorded significantly highest DHA (2.79 μg TPF $hr^{-1}g^{-1}$) as well as labile carbon (355.0 μg g^{-1} of soil) while application of 25 kg N (compost) recorded significantly highest MBC of 162.0 μg g^{-1} of soil. Among the physical soil quality parameters, both bulk density as well as mean weight diameter were significantly influenced by the management treatments and were observed to vary from 1.51 to 1.71 Mg m^{-3} and 0.17 to 0.35 mm respectively across the treatments (Fig 103).

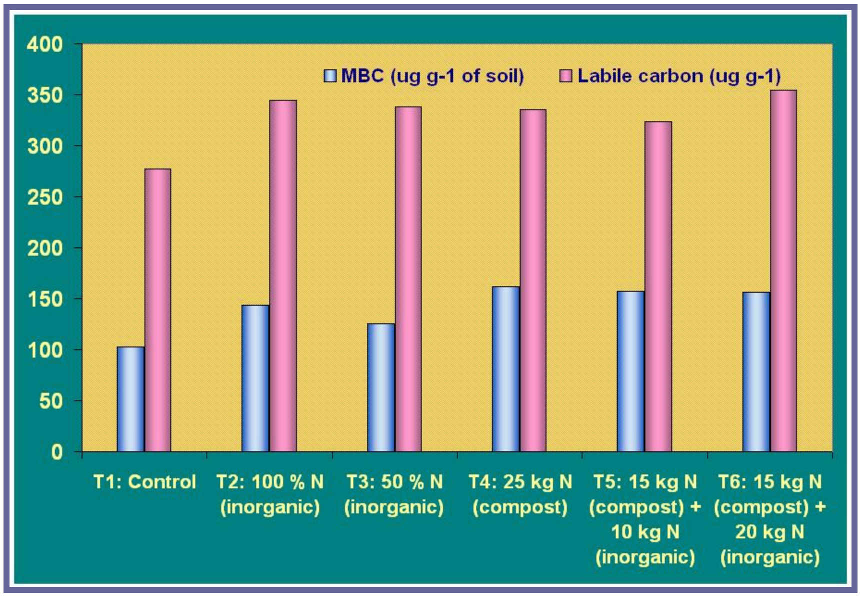


Fig 102: Effect of different integrated nutrient management treatments on biological soil quality parameters under maize-black gram system in Inceptisols of Rakhdhiansar

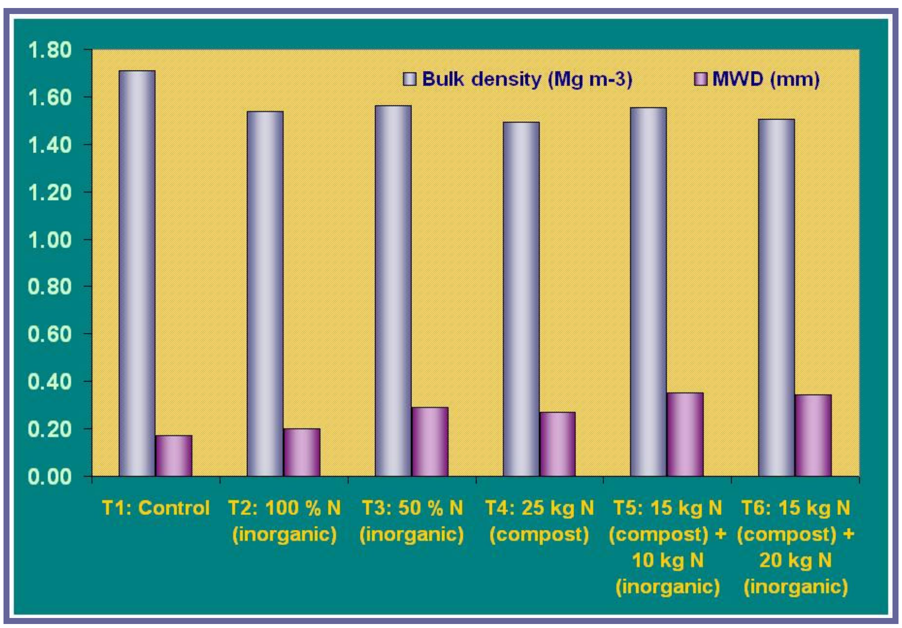


Fig 103: Effect of different integrated nutrient management treatments on physical soil quality parameters under maize-black gram system in Inceptisols of Rakhdhiansar

Table 124: Effect of different integrated nutrient management treatments on biological and physical soil quality parameters under maize-black gram system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	DHA (µg TPF $hr^{-1}g^{-1}$)	MBC (µg g^{-1} of soil)	LC (µg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	T1: Control	1.76	102.7	277.5	1.71	0.17
2	T2: 100 % N (inorganic)	2.11	143.9	344.2	1.54	0.20
3	T3: 50 % N (inorganic)	2.01	125.3	338.2	1.56	0.29
4	T4: 25 kg N (compost)	2.25	162.0	335.1	1.49	0.27
5	T5: 15 kg N (compost) + 10 kg N (inorganic)	2.67	156.8	323.8	1.55	0.35
6	T6: 15 kg N (compost) + 20 kg N (inorganic)	2.79	156.4	355.0	1.51	0.34
	CD @ 0.05	0.41	16.9	33.8	0.11	0.08

4.2.29.1. Key indicators and soil quality assessment

4.2.29.2. Results of Principal Component Analysis

The data on influence of integrated nutrient management treatments practiced under maize-black gram system on 19 soil quality indices has been statistically analyzed and it was observed that out of 19 soil quality parameters, 7 variables viz., pH, EC, available K, Mg, Fe, Cu and Mn were insignificant and hence were dropped from further PCA analysis. In the PCA of 12 variables, two PCs had eigen values >1 and explained 74.2 % variance in the data set (Table 125). In PC1, five variables viz., exchangeable Ca, available Zn, B, microbial biomass carbon and bulk density were the highly weighted variables while in PC2 only single variable ie available N is highly weighted. Correlation analysis was run between the variables qualified under PC1. The correlation matrix showed that the parameters were significant and well correlated (Table 126). But considering their importance in these soils, all the highly weighted variables under PC1 were retained to be included under MDS. Hence, the final MDS included exchangeable Ca, available N, available Zn, & B, microbial biomass carbon and bulk density and were termed the key indicators for maize-black gram system practiced in Inceptisols of Rakhdhiansar.

Table 125: Principal component analysis of soil quality parameters as influenced by maize-black gram system in Inceptisols of Rakhdhiansar

	PC1	PC2
Total Eigen values	6.999	1.166
% of Variance	63.626	10.597
Cumulative %	63.626	74.223
Eigen Vectors		
OC	0.814	0.163
N	0.450	0.763
Ca	0.906	0.123
S	0.716	-0.269
Zn	0.891	0.017
B	0.914	-0.004
DHA	0.749	-0.417
MBC	0.899	0.033
LC	0.770	0.211
BD	-0.823	-0.088
MWD	0.728	-0.493

Table 126: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs	Ca	Zn	B	MBC	BD
Ca	1.00	0.826**	0.829**	0.738**	-0.839**
Zn	0.826**	1.00	0.865**	0.780**	-0.800**
B	0.829**	0.865**	1.00	0.812**	-0.675**
MBC	0.738**	0.780**	0.812**	1.00	-0.750**
BD	-0.839**	-0.800	-0.675**	-0.750**	1.00
Correlation sum	4.232	4.271	4.181	4.08	4.064

**correlation is significant at P = 0.01 level

4.2.29.3. Soil quality indices

Soil quality indices were computed using six soil quality indicators viz., the available N, exchangeable Ca, available Zn & B, microbial biomass carbon and bulk density. Soil quality indices varied from 2.68 to 4.17 across the management treatments (Table 127). In order to have an easy comparison, soil quality indices were reduced to a scale of one termed as the relative soil quality indices, which varied from 0.63 to 0.97 across the management treatments (Fig 104). Among all the treatments practiced under maize-black gram system, application of 25 kg N compost had significantly highest RSQI of 0.97 which was at par with application of 15 kg N (compost) + 20 kg N (inorganic) (0.94). Irrespective of their statistical significance, the relative order of performance of the treatments in influencing the soil quality indices were: T4: 25 kg N (compost) (4.17) > T6: 15 kg N (compost) + 20 kg N (inorganic) (4.05) > T5: 15 kg N (compost) + 10 kg N (inorganic) (3.75) > T2: 100 % N (inorganic) (3.55) > T3: 50 % N (inorganic) (3.46) > T1: Control (2.68). The percent contributions of the key indicators towards the soil quality indices were as follows: available N (3.49%), exchangeable Ca (19.6%), available Zn (16.6%), available B (19.3%), microbial biomass carbon (19.7%), bulk density (21.4%) (Fig 105).

Table 127: Soil quality indices (SQI) and relative soil quality indices (RSQI) as influenced by different integrated nutrient management treatments under maize-black gram system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	SQI	RSQI
1	T1: Control	2.68	0.63
2	T2: 100 % N (inorganic)	3.55	0.83
3	T3: 50 % N (inorganic)	3.46	0.81
4	T4: 25 kg N (compost)	4.17	0.97
5	T5: 15 kg N (compost) + 10 kg N (inorganic)	3.75	0.87
6	T6: 15 kg N (compost) + 20 kg N (inorganic)	4.05	0.94
	CD @ 0.05	0.29	0.07

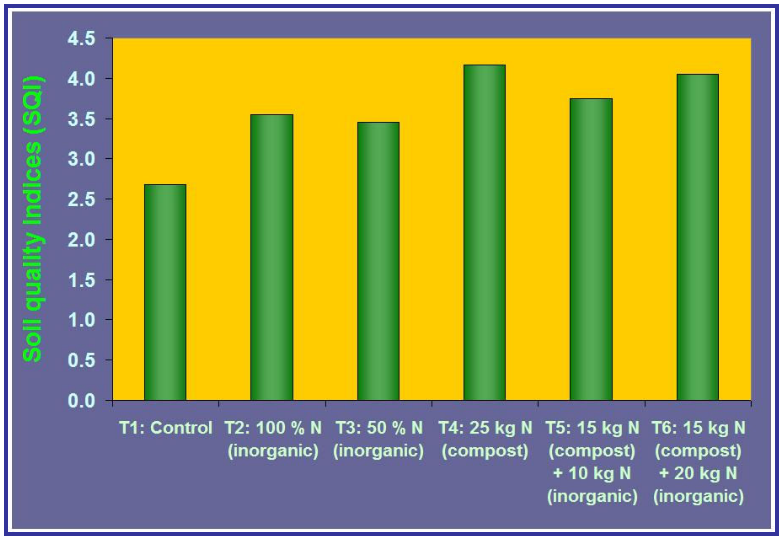


Fig 104: Soil quality indices (SQI) as influenced by different integrated nutrient management treatments under maize-black gram system in Inceptisols of Rakhdhiansar

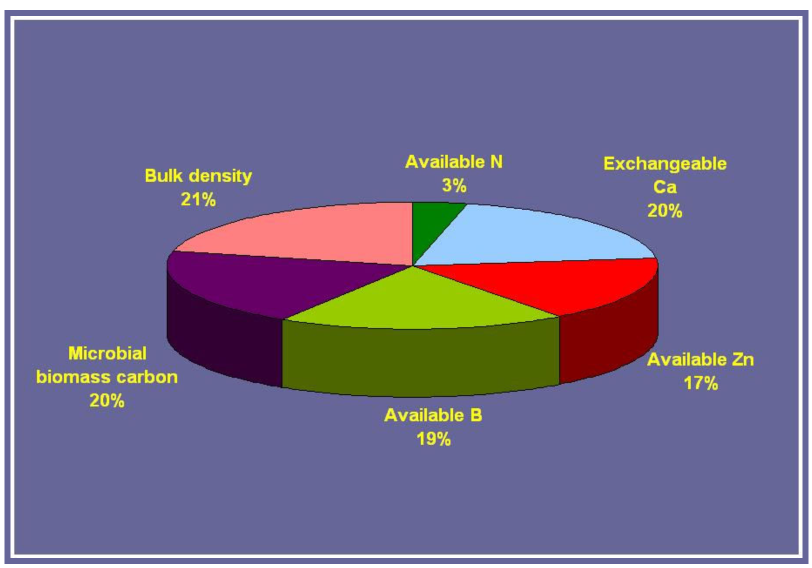


Fig 105: Percent contribution of key indicators towards soil quality indices (SQI) as influenced by different integrated nutrient management treatments under maize-black gram system in Inceptisols of Rakhdhiansar

4.2.30. Experiment 2: Permanent manurial trial

Soils in dryland region are loosing productivity due to continuous double cropping and poor use of inorganics in imbalanced proportions and negligible use of organics. The farmers of Kandi belt generally apply single fertilizer (urea only), which is supplemented with FYM. The prices of inorganic fertilizer being frequently raised and therefore, they are becoming out of reach of the poor farmers of Kandi belt. To evaluate the efficiency of balanced fertilizers compared with different combinations of organics and inorganics, to find out the suitable combinations of organics and inorganics for maize in Kandi belt, to minimize the use of inorganics and to make these soils fit for sustainable agriculture, a permanent manurial trial was taken up to stabilize yield and improve properties over a period of time. The experiment was initiated during the year 1995 in randomized block design with 10 nutrient management treatments in four replications using maize (Composite Mansar) as test crop. In order to assess soil quality, in the present study, out of the 10 treatments, seven treatments viz., T1: Control; T2: 100% recommended NPK levels (60:40:20 kg ha^{-1}); T3: 50% recommended NPK levels; T4: 50% recommended N through crop residue; T5: 50% recommended N through FYM; T6: 50% recommended NPK + 50% recommended N through crop residue and T7: 50% recommended NPK + 50% recommended N through FYM were chosen.

Soil quality assessment studies were conducted during 2005 i.e. after 11 years of experimentation and the data obtained for these soil quality attributes are presented in Tables 128 to 130 & Fig 106 to 110 and are discussed hereunder.

From the data, it was observed that soil pH was found to be slightly acidic with values ranging from 6.31 to 6.65 across the management treatments. Of all the treatments, addition of 50% N through FYM showed significantly highest pH value of 6.65 tending towards neutrality and was at par with the application of 50% NPK + 50% N through FYM (6.56) and 50% NPK + 50% N through crop residue (6.53). It was observed that the EC values of the treatment i.e. application of 50% N through FYM recorded significantly higher EC compared to other treatments. Organic carbon in these soils varied from 2.72 to 3.92 across the management treatments. Significantly highest organic carbon content was observed with application of 50% NPK + 50% N through crop residue (3.92 g kg^{-1}) which was at par with other treatments. Among the macronutrients, both available N and P were significantly influenced by the management treatments while available K was not significantly influenced. Available N status was low in these soils ranging from 132.7 to 173.9 kg ha^{-1} while available P, which was found to be high, ranged from 19.7 to 38.0 kg ha^{-1} across the management treatments. From the data, it was observed that, in terms of available N content, the management treatments had significant difference with respect to control but were at par among themselves. However, the highest available N content was observed with application of 50% NPK + 50% N through FYM (173.9 kg ha^{-1}). Available P content was significantly high with application of 50% NPK + 50% N through crop residue (38.0 kg ha^{-1}) which was at par with application of 50% N through crop residue as well as FYM. Irrespective of the statistical insignificance, available K varied from 169.4 to 228.7 kg ha^{-1} across the management treatments (Fig 106).

Table 128: Effect of different manurial treatments on physico-chemical and chemical soil quality parameters under Maize system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	pH	EC dS m^{-1}	OC (g kg^{-1})	N	P	K
					(kg ha^{-1})		
1	T1: Control	6.42	0.08	2.72	132.7	19.7	169.4
2	T2: 100% NPK (60:40:20 kg/ha)	6.44	0.07	3.40	150.1	28.6	211.7
3	T3: 50% NPK	6.31	0.07	3.09	142.6	23.4	228.7
4	T4: 50%N (crop residue)	6.34	0.07	3.10	148.2	30.2	224.9
5	T5: 50%N (FYM)	6.65	0.12	3.43	151.4	32.0	223.4
6	T6: 50% NPK + 50% N (Crop residue)	6.53	0.07	3.92	163.0	38.0	214.6
7	T7:50% NPK + 50% N (FYM)	6.56	0.09	3.65	173.9	24.7	213.6
	CD @ 0.05	0.20	0.03	0.65	18.4	9.37	NS

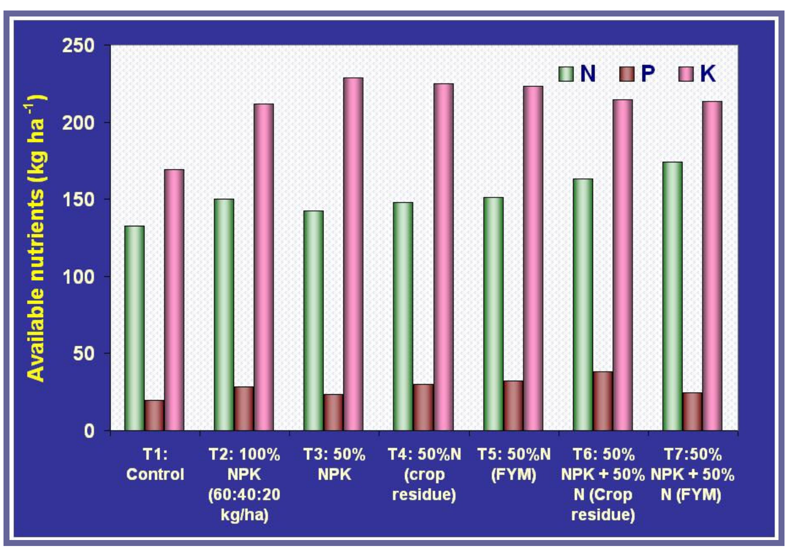


Fig 106: Influence of different manurial treatments on chemical soil quality parameters (macronutrients) under Maize system in Inceptisols of Rakhdhiansar

Among the secondary nutrients, exchangeable Ca as well as available S were significantly influenced by the management treatments while exchangeable Mg did not show any significance and varied from 0.45 to 0.65 across the management treatments (Table 129 & Fig 107). In case of exchangeable Ca as well as available S, the significant influence of the treatments was with respect to control but not among themselves. However, exchangeable Ca varying between 2.56 and 3.65 c mol kg^{-1} and available S varying from 9.67 to 18.6 kg ha^{-1} across the treatments was found to be significantly highest under application of 50% N through FYM. Among the micronutrients, the influence of the management treatments was significant for available Zn, Fe and Mn but not for Cu and B. However, irrespective of their significance, available Cu and B varied between 0.68 to 0.83 µg g^{-1} and 0.32 to 0.47 µg g^{-1} across the management treatments. The management treatments which recorded significantly highest available Zn, Fe and B were: 50% NPK + 50% N through FYM for Zn (2.52 µg g^{-1}), 50% NPK + 50% N through crop residue for Fe (17.2 µg g^{-1}), and 50% N through FYM for available B (0.47 µg g^{-1}) which were at par with other treatments also (Fig 108).

Table 129: Effect of different manurial treatments on chemical soil quality parameters under Maize system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		cmol kg^{-1}		(kg ha^{-1})	µg g^{-1}				
1	T1: Control	2.56	0.45	9.67	1.45	11.0	0.68	12.5	0.32
2	T2: 100% NPK (60:40:20 kg/ha)	3.24	0.53	15.9	2.34	13.3	0.75	19.2	0.40
3	T3: 50% NPK	3.03	0.56	16.5	2.07	13.7	0.71	17.0	0.38
4	T4: 50%N (crop residue)	3.06	0.56	14.3	2.30	13.1	0.72	18.3	0.42
5	T5: 50%N (FYM)	3.65	0.65	18.6	2.50	14.3	0.75	17.5	0.47
6	T6: 50% NPK + 50% N (Crop residue)	3.37	0.61	16.1	2.19	17.2	0.83	20.5	0.41
7	T7:50% NPK + 50% N (FYM)	3.07	0.57	17.7	2.52	15.0	0.72	16.9	0.41
	CD @ 0.05	0.63	NS	4.74	0.55	3.23	NS	3.69	NS

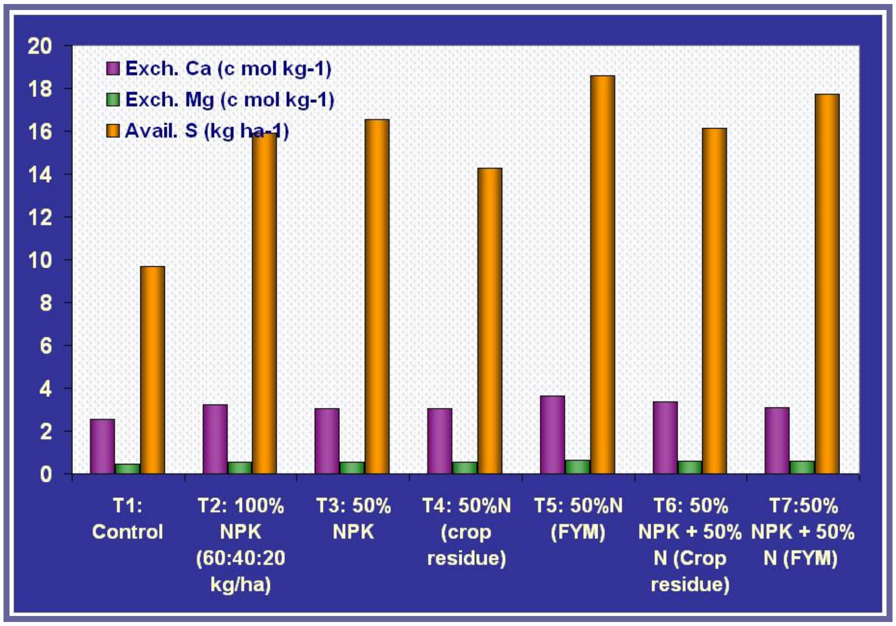


Fig 107: Influence of different manurial treatments on chemical soil quality parameters (secondary nutrients) under Maize system in Inceptisols of Rakhdhiansar

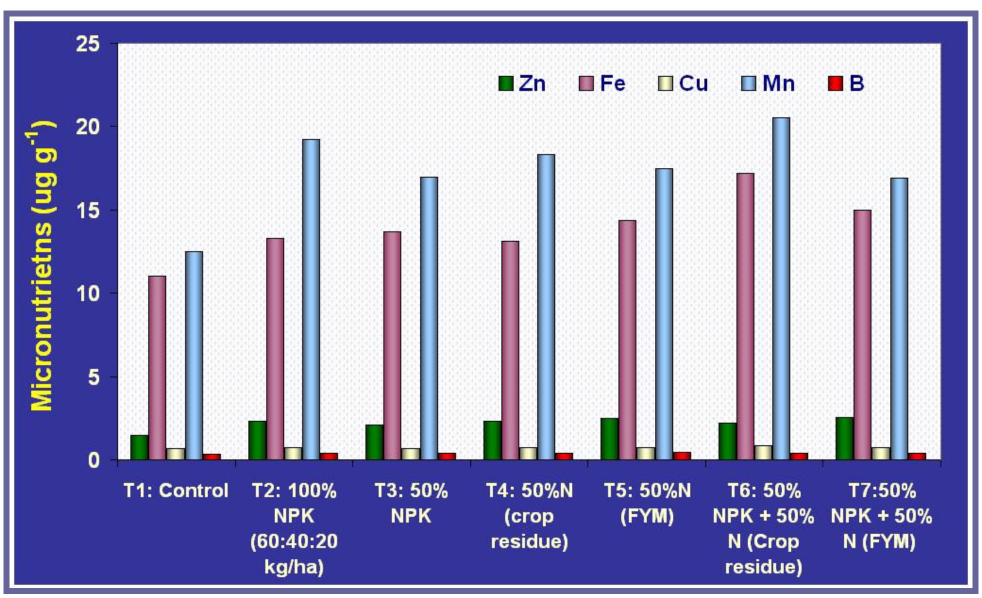


Fig 108: Influence of different manurial treatments on chemical soil quality parameters (micronutrients) under Maize system in Inceptisols of Rakhdhiansar

All the biological soil quality parameters viz., dehydrogenase (DHA), microbial biomass carbon (MBC) as well as labile carbon (LC) were significantly influenced by the management treatments (Table 130 & Fig 109). Dehydrogenase activity ranging from 1.96 to 2.85 μg TPF $hr^{-1}g^{-1}$ across the management treatments was found to be significantly high with application of 50%N through FYM (2.85 μg TPF $hr^{-1}g^{-1}$) followed by application of 50% NPK + 50% N through FYM (2.45 μg TPF $hr^{-1}g^{-1}$). Microbial biomass varied from 95.7 to 172.1 μg g^{-1} of soil across the management treatments. Significantly highest MBC was observed under application of 50% NPK + 50% N through FYM (172.1μg g^{-1} of soil) which was at par with 50% NPK + 50% N through crop residue (166.7 μg g^{-1} of soil) followed by 100% NPK (60:40:20 kg/ha) (151.9 μg g^{-1} of soil). Significantly highest labile carbon was observed with application of 50% N through FYM (337.9 μg g^{-1} of soil) while the lowest was observed with 100% NPK (60:40:20 kg/ha) (259.5 μg g^{-1} of soil) which was lower to that observed under control plot. The physical soil quality parameters viz., bulk density and mean weight diameter were also significantly influenced by the management treatments especially with respect to control but were at par with each other. Application of 50% N through FYM and 50% NPK recorded lowest bulk density of 1.48 Mg m^{-3} and were at par with other treatments. Significantly highest mean weight diameters were observed with application of 50% NPK + 50% N (FYM) (0.32 mm) and 50% NPK + 50% N through crop residue (0.30mm) and were at par with other treatments also (Fig 110).

Table 130: Effect of different manurial treatments on biological and physical soil quality parameters under Maize system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	DHA (μg TPF $hr^{-1}g^{-1}$)	MBC (μg g^{-1} of soil)	LC (μg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	T1: Control	1.96	95.7	261.5	1.66	0.16
2	T2: 100% NPK (60:40:20 kg/ha)	2.17	151.9	259.5	1.58	0.25
3	T3: 50% NPK	2.30	136.1	324.9	1.48	0.25
4	T4: 50%N (crop residue)	2.15	127.1	299.1	1.51	0.28
5	T5: 50%N (FYM)	2.85	141.8	337.9	1.48	0.27
6	T6: 50% NPK + 50% N (Crop residue)	2.30	166.7	328.3	1.54	0.30
7	T7:50% NPK + 50% N (FYM)	2.45	172.1	326.3	1.52	0.32
	CD @ 0.05	0.36	21.1	32.1	0.09	0.09

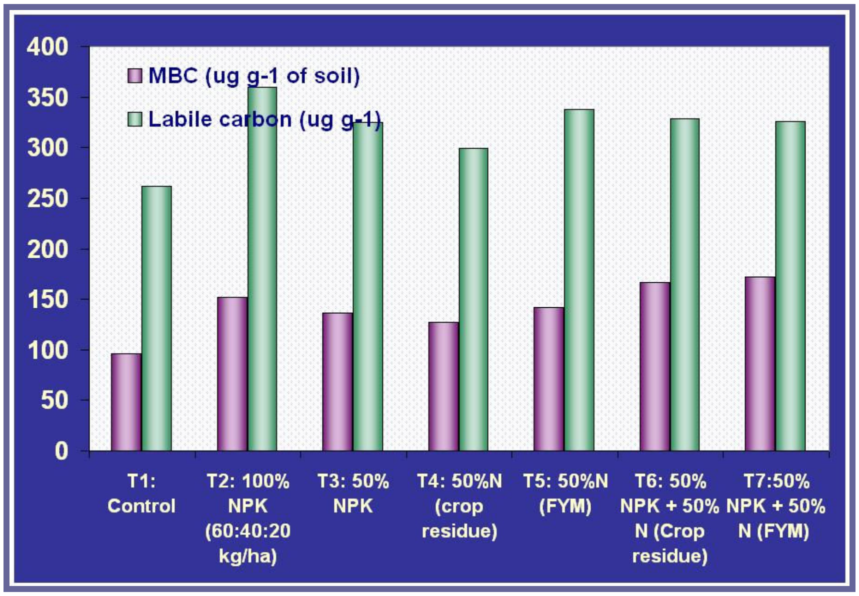


Fig 109: Effect of different manurial treatments on biological soil quality parameters under Maize system in Inceptisols of Rakhdhiansar

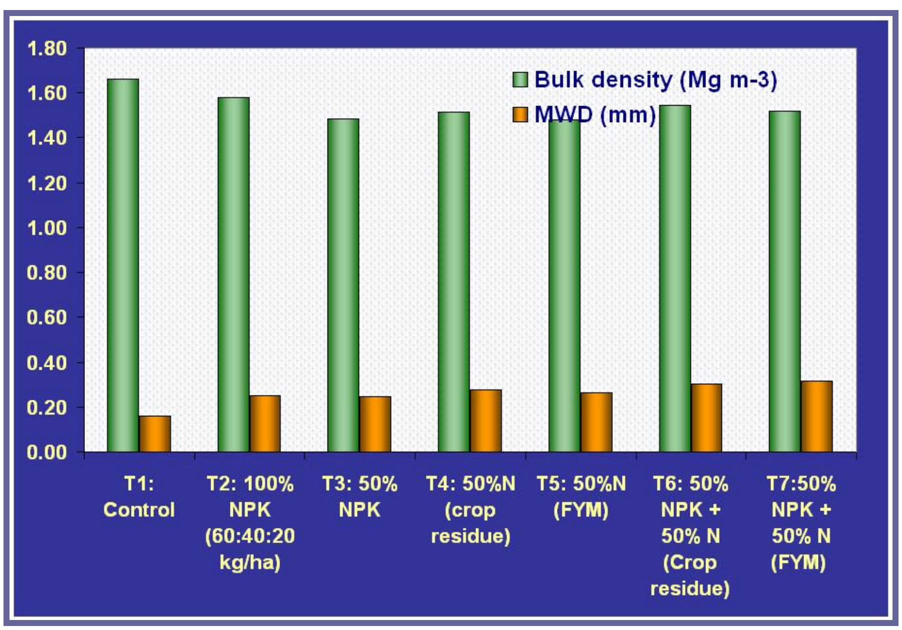


Fig 110: Effect of different manurial treatments on physical soil quality parameters under Maize system in Inceptisols of Rakhdhiansar

4.2.30.1. Key indicators and soil quality assessment

4.2.30.2. Results of Principal Component Analysis

The data on influence of integrated nutrient management treatments practiced under maize system on 19 soil quality indices has been statistically analyzed and it was observed that out of 19 soil quality parameters, 4 variables viz., available K, exchangeable Mg, available Cu and B were insignificant and hence were dropped from further PCA analysis. In the PCA of 15 variables, five PCs had eigen values >1 and explained 81.2 % variance in the data set (Table 131). In PC1, two variables viz., available S and microbial biomass carbon were the highly weighted variables. The variables qualified in the subsequent PCs were EC and dehydrogenase assay in PC2; pH in PC3; available P in PC4 and organic carbon and available Zn in PC5. The correlation analysis performed between the variables qualified in PC1, PC2 and PC5 individually revealed that none of the variables were well correlated ($r > 0.70$) within these PCs and hence were retained in the final MDS (Table 132). So, on the whole, the final MDS included eight variables viz., pH, EC, organic carbon, available P, available S, available Zn, dehydrogenase assay and microbial biomass carbon and were termed as the key indicators for maize system in Inceptisols of Rakhdhiansar.

Table 131: Principal component analysis of soil quality parameters as influenced by maize system in Inceptisols of Rakhdhiansar

	PC1	PC2	PC3	PC4	PC5
Total Eigen values	6.649	1.931	1.392	1.193	1.022
% of Variance	44.326	12.876	9.279	7.957	6.811
Cumulative %	44.326	57.202	66.481	74.438	81.249
Eigen Vectors					
pH	0.514	0.109	**0.607**	0.292	0.464
EC	0.262	**0.669**	0.545	-0.293	-0.027
OC	0.757	-0.327	-0.121	0.012	**0.431**
N	0.679	-0.177	0.223	-0.062	-0.033
P	0.631	-0.155	0.030	**-0.636**	0.300
Ca	0.581	0.535	-0.394	0.092	0.285
S	**0.778**	0.119	0.142	-0.063	-0.190
Zn	0.718	-0.003	0.209	0.259	**-0.439**
Fe	0.750	-0.439	0.199	-0.063	0.023
Mn	0.742	-0.353	-0.057	-0.173	-0.194
DHA	0.601	**0.675**	0.019	0.224	-0.092
MBC	**0.855**	-0.200	-0.157	0.238	-0.063
LC	0.692	0.045	-0.407	0.417	0.150
BD	-0.455	-0.437	0.447	0.457	0.042
MWD	0.732	-0.056	-0.088	-0.100	-0.378

Table 132: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs		
PC1	S	MBC
S	1.00	0.554**
MBC	0.554**	1.00
Correlation sum	1.554	1.554
PC2	EC	DHA
EC	1.00	0.508**
DHA	0.508**	1.00
Correlation Sum	1.508	1.508
PC5	OC	Zn
OC	1.00	0.316
Zn	0.316	1.00
Correlation Sum	1.316	1.316

**correlation is significant at P = 0.01 level

4.2.30.3. Soil quality indices

Soil quality indices were computed for this maize system using the eight key indicators retained in the final MDS viz., pH, EC, organic carbon, available P, available S, available Zn, dehydrogenase assay and microbial biomass carbon. It was observed that the manurial treatments had significant influence on soil quality indices, which varied from 0.97 to 1.52 across the management treatments, while the relative soil quality indices varied from 0.62 to 0.98 (Table 133 & Fig 111). Of the different manurial treatments applied to maize crop, application of 50%N (FYM) as well as application of 50% NPK + 50% N (FYM) performed equally well in maintaining the soil quality with a SQI value of 1.52 and these were at par with 50% NPK + 50% N (Crop residue) (1.46). However, the control plot recorded the lowest SQI of 0.97. Irrespective of their statistical significance, the relative order of performance of the manurial treatments in terms of influencing soil quality indices were: T5: 50%N (FYM) (1.52) > T7: 50% NPK + 50% N (FYM) (1.52) > T6: 50% NPK + 50% N (Crop residue) (1.46) > T2: 100% NPK (60:40:20 kg ha^{-1}) (1.38) > T3: 50% NPK (1.33) > T4: 50%N (crop residue) (1.25) > T1: Control (0.97). The percent contribution of key indicators towards soil quality indices was computed and it was observed that among all the key indicators, available S and microbial biomass carbon contributed a maximum percentage of 31.9 and 31.8% respectively while the other indicators contributed less viz., pH (8.05%), EC (6.01%), organic carbon (4.87%), available P (4.45%), available Zn (4.56%) and dehydrogenase assay (8.36%) (Fig 112).

Table 133: Soil quality indices (SQI) and relative soil quality indices (RSQI) as influenced by different manurial treatments under maize system in Inceptisols of Rakhdhiansar

Sno	Name of the treatments	SQI	RSQI
1	T1: Control	0.97	0.62
2	T2: 100% NPK (60:40:20 kg ha^{-1})	1.38	0.89
3	T3: 50% NPK	1.33	0.85
4	T4: 50%N (crop residue)	1.25	0.80
5	T5: 50%N (FYM)	1.52	0.98
6	T6: 50% NPK + 50% N (Crop residue)	1.46	0.94
7	T7: 50% NPK + 50% N (FYM)	1.52	0.97
	CD @ 0.05	0.14	0.09

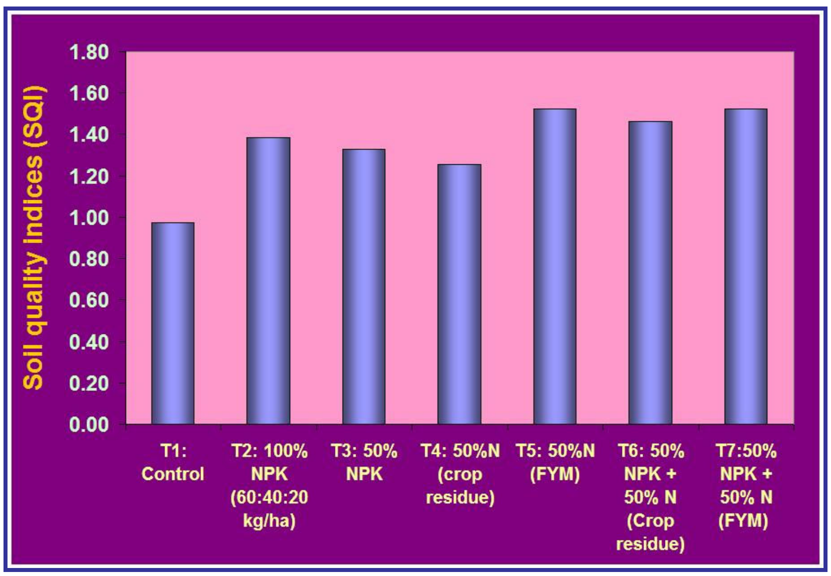


Fig 111: Soil quality indices (SQI) as influenced by different manurial treatments under maize system in Inceptisols of Rakhdhiansar

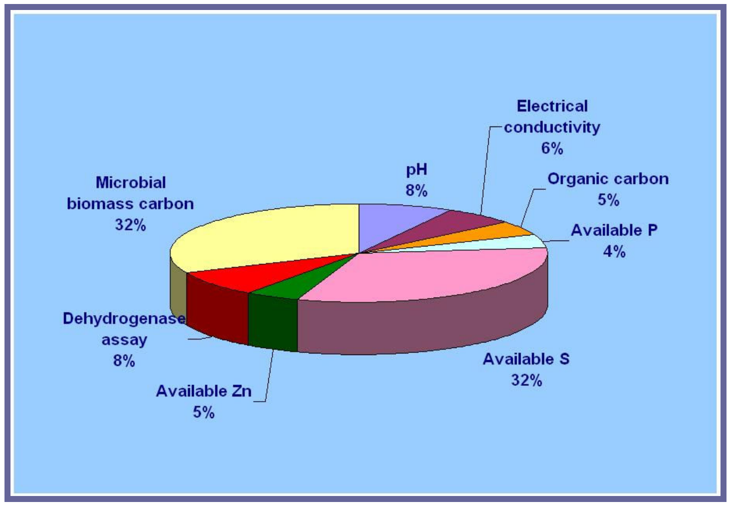


Fig 112: Percent contribution of key indicators towards soil quality indices (SQI) as influenced by different manurial treatments under maize system in Inceptisols of Rakhdhiansar

4.2.31. Experiment 3: Nutrient management in maize-wheat rotation

Soils of this region are generally low in organic matter and also have low moisture retention capacity. A little prolonged drought affects the crop to such an extent that the yield of the main cereal crops (maize and wheat) is poor. The aim of the experiment was to use available green manuring (sunhemp in-situ and addition of green leaves of leuceana) and FYM as a source of nitrogen and for improvement of soil conditions in maize-wheat sequence. In order to find out the effects of FYM and green manuring practice (sunhemp and leuceana leaves), along with different doses of nitrogen on the grain yield of maize and its subsequent effect on wheat, the experiment was initiated during the year 2001 in a randomized block design with ten nutrient management treatments in three replications using maize (Kanchan-510) as the test crop. Out of the 10 treatments, only five treatments viz., T1: Control, T2: FYM @ 10 t ha^{-1} + 20 kg N ha^{-1}, T3: FYM @ 10 t ha^{-1} + 30 kg N ha^{-1}, T4: FYM @ 10 t ha^{-1} + 40 kg N ha^{-1} and T5: Green manuring with Sunhemp + 20 kg N ha^{-1} were selected for the soil quality assessment studies. Soil quality studies were undertaken after fifth year of the experimentation.

The results presented in Table 134 revealed that the nutrient management treatments had no significant influence on the physico-chemical parameters viz., pH and electrical conductivity. However, the soil pH varied from near neutral to neutral ranging from 6.75 to 7.22, while electrical conductivity varied from 0.09 to 0.13 dS m^{-1}. Soils were observed to be medium in organic carbon content varying from 3.18 to 4.53 g kg^{-1}. Application of FYM @ 10 t ha^{-1} + 40 kg N ha^{-1} recorded significantly highest organic carbon content of 4.53 g kg^{-1} and was at par with other treatments since all the treatments received either FYM or green manure as a component of nutrient source which could improve and maintain the organic carbon in a long run. The chemical soil quality parameters i.e. available N, P and K were significantly influenced by the management treatments. Available N was low varying from 130.0 to 164.7 kg ha^{-1}, available P was high ranging from 19.7 to 34.0 kg ha^{-1} and available K also being high ranged from 194 to 262.8 kg ha^{-1}. Of all the treatments, application of FYM @ 10 t ha^{-1} + 40 kg N ha^{-1} significantly highest available N (164.7 kg ha^{-1}), available P (34.0 kg ha^{-1} and available K (262.8 kg ha^{-1}) and was at par with other treatments (Fig 113).

Table 134: Effect of different nutrient management treatments on physico-chemical and chemical soil quality parameters under maize-wheat rotation system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	pH	EC dS m^{-1}	OC ($g\ kg^{-1}$)	N	P	K
					($kg\ ha^{-1}$)		
1	T1: Control	6.75	0.09	3.18	130.0	19.7	194.0
2	T2: FYM @ 10 t ha^{-1} + 20 kg N ha^{-1}	7.22	0.11	4.30	140.5	33.9	243.2
3	T3: FYM @ 10 t ha^{-1} + 30 kg N ha^{-1}	7.12	0.10	4.35	150.7	32.4	251.2
4	T4: FYM @ 10 t ha^{-1} + 40 kg N ha^{-1}	6.96	0.13	4.53	164.7	34.0	262.8
5	T5: Green manuring with Sunhemp + 20 kg N ha^{-1}	6.82	0.07	4.17	144.6	30.6	260.8
	CD @ 0.05	NS	NS	0.91	18.8	8.77	35.4

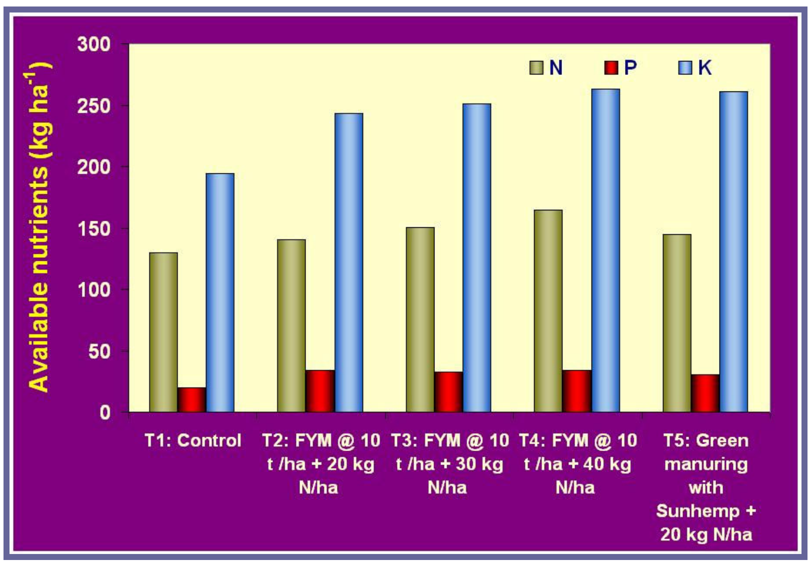


Fig 113: Influence of different nutrient management treatments on chemical soil quality parameters (macronutrients) under maize-wheat rotation system in Inceptisols of Rakhdhiansar

Among the secondary nutrient parameters, available S was significantly influenced by the management treatments while exchangeable Ca and Mg were not (Table 135). However, exchangeable Ca varied from 2.97 to 3.83 cmol kg^{-1} and exchangeable Mg from 0.47 to 0.58 c mol kg^{-1} across the management treatments. Available S was found to be significantly highest under green manuring with Sunhemp + 20 kg Nha^{-1} (19.5 kg ha^{-1}) which was at par with other treatments barring control plot (Fig 114). Among the micronutrients, the significant influence of the management treatments was observed on available Fe and Mn while no conspicuous influence was observed on Zn, Cu and B. However, irrespective of their significance, available Zn was found high in soils varying from 0.75 to 1.48 µg g^{-1}, Cu from 0.78 to 0.95 µg g^{-1} and B from 0.33 to 0.57 µg g^{-1}across the management treatments. Available Fe and Mn ranging high in these soils varied from 9.19 to 15.0 µg g^{-1} and 11.1 to 16.6 µg g^{-1} respectively across the management treatments. Application of FYM @ 10 t ha^{-1} + 40 kg N ha^{-1} recorded significantly highest available Fe of 15.0 µg g^{-1} while application of FYM @ 10 t ha^{-1} + 30 kg N ha^{-1} recorded significantly highest available Mn of 16.6 µg g^{-1} which was at par with other treatments.

Table 135: Effect of different nutrient management treatments on chemical soil quality parameters under maize-wheat rotation system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		cmol kg^{-1}		(kg ha^{-1})	µg g^{-1}				
1	T1: Control	2.97	0.47	11.6	0.75	9.19	0.78	11.1	0.33
2	T2: FYM @ 10 t ha^{-1} + 20 kg N ha^{-1}	3.67	0.55	16.0	1.61	11.7	0.84	16.2	0.46
3	T3: FYM @ 10 t ha^{-1} + 30 kg N ha^{-1}	3.83	0.58	18.1	1.73	11.3	0.95	16.6	0.51
4	T4: FYM @ 10 t ha^{-1} + 40 kg N ha^{-1}	3.57	0.55	18.7	1.49	15.0	0.89	15.6	0.64
5	T5: Green manuring with Sunhemp + 20 kg N ha^{-1}	3.70	0.58	19.5	1.55	11.7	0.91	16.0	0.50
	CD @ 0.05	NS	NS	5.14	0.49	2.91	NS	3.51	0.13

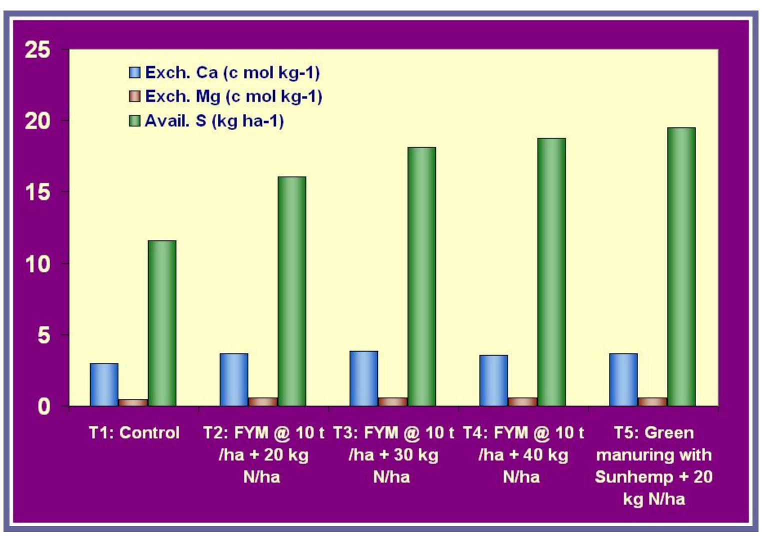


Fig 114: Effect of different nutrient management treatments on chemical soil quality parameters (secondary nutrients) under maize-wheat rotation system in Inceptisols of Rakhdhiansar

The nutrient management treatments showed a conspicuous influence on the biological soil quality parameters viz., DHA, MBC and LC. Dehydrogenase activity varied between 1.98 to 2.68 μg TPF $hr^{-1}g^{-1}$ while the microbial biomass carbon varied between 107.1 to 171.4 μg g^{-1} of soil across the management treatments (Table 136 & Fig 115). The nutrient management treatments performed similarly in influencing and maintaining DHA and MBC, where application of FYM @ 10 t ha^{-1} + 40 kg Nha^{-1} significantly maintained highest DHA and MBC of 2.68 μg TPF $hr^{-1}g^{-1}$ and 171.4 μg g^{-1} of soil respectively which was at par with green manuring with sunhemp + 20 kg N ha^{-1} with corresponding values of 2.47 μg TPF $hr^{-1}g^{-1}$ and 166.2 μg g^{-1} of soil respectively. Similar to DHA and MBC, labile carbon content was significantly highest under application of FYM @ 10 t ha^{-1} + 40 kg N ha^{-1} (363.8 μg g^{-1} of soil) which was at par with two other treatments. The physical soil quality parameters were significantly influenced by the management treatments and bulk density varied from 1.46 to 1.65 Mg m^{-3} while mean weight diameter varied from 0.14 to 0.30 mm across the treatments (Fig 116).

Table 136: Effect of different nutrient management treatments on biological and physical soil quality parameters under maize-wheat rotation system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	DHA (μg TPF $hr^{-1}g^{-1}$)	MBC (μg g^{-1} of soil)	LC (μg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	T1: Control	1.98	107.1	236.5	1.65	0.14
2	T2: FYM @ 10 t ha^{-1} + 20 kg N ha^{-1}	2.27	133.9	285.5	1.48	0.22
3	T3: FYM @ 10 t ha^{-1} + 30 kg N ha^{-1}	2.34	155.0	361.1	1.47	0.25
4	T4: FYM @ 10 t ha^{-1} + 40 kg N ha^{-1}	2.68	171.4	363.8	1.46	0.30
5	T5: Green manuring with Sunhemp + 20 kg N ha^{-1}	2.47	166.2	308.5	1.48	0.30
	CD @ 0.05	0.30	16.5	27.6	0.07	0.05

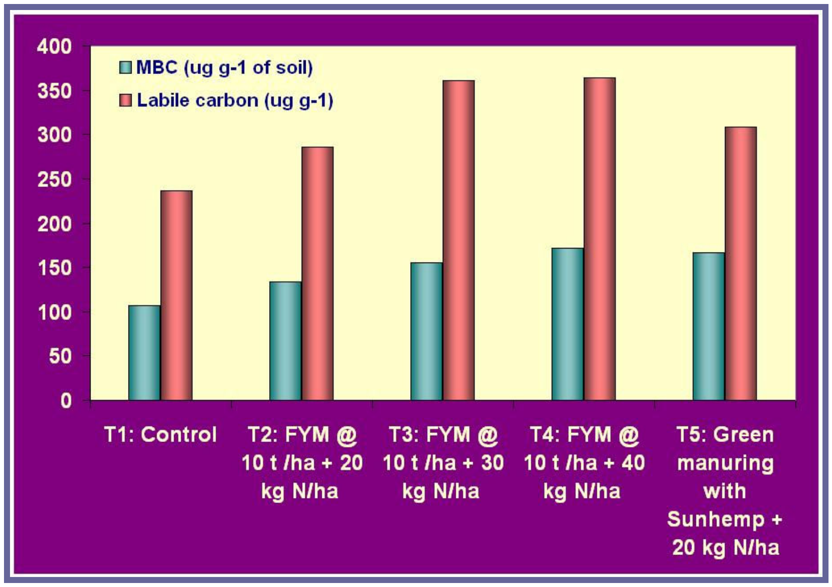


Fig 115: Effect of different nutrient management treatments on biological soil quality parameters under maize-wheat rotation system in Inceptisols of Rakhdhiansar

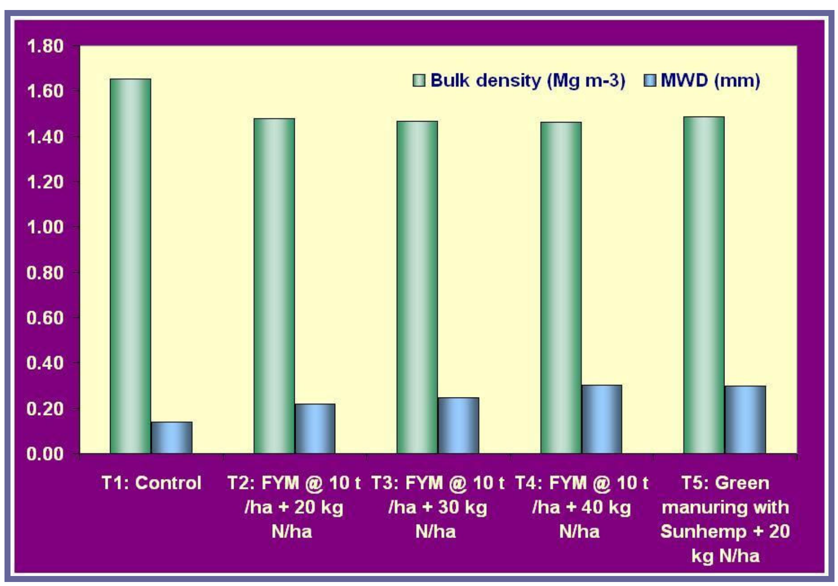


Fig 116: Effect of different nutrient management treatments on physical soil quality parameters under maize-wheat rotation system in Inceptisols of Rakhdhiansar

4.2.31.1. Key indicators and soil quality assessment

4.2.31.2. Results of Principal Component Analysis

The influence of the nutrient management treatments practiced under maize-wheat rotation on 19 soil quality parameters when statistically analyzed revealed that pH, electrical conductivity, exchangeable Ca & Mg and available Cu were statistically insignificant and hence were not subjected to PCA analysis. In the PCA run with 14 variables, only two PCs with had eigen values > 1 and explained 79.0% variance in the data set (Table 137). The variables qualified in PC1 were: organic carbon, available P, available K, available Zn, microbial biomass carbon, labile carbon, bulk density and mean weight diameter, while in PC2, only two variables viz., available N and available Fe were highly weighted. The correlation coefficients (Table 138) between the variables qualified in PC1 despite being significant, except labile carbon, were retained based on their critical role in these Inceptisol soils. The correlations run between the variables in PC2 did not reveal significant correlation and hence were retained for the final MDS. Hence, the variables, which were retained for the final MDS for computing the soil quality indices, included organic carbon, available N, available P, available K, available Fe & Zn, microbial biomass carbon, bulk density and mean weight diameter.

Table 137: Principal component analysis of soil quality parameters as influenced by maize-wheat rotation systems in Inceptisols of Rakhdhiansar

	PC1	PC2
Total Eigen values	9.503	1.553
% of Variance	67.876	11.096
Cumulative %	67.876	78.972
Eigen Vectors		
OC	**0.832**	-0.315
N	0.666	**0.524**
P	**0.844**	-0.284
K	**0.910**	-0.101
S	0.749	-0.424
Zn	**0.820**	-0.335
Fe	0.709	**0.504**
Mn	0.779	-0.389
B	0.810	0.276
DHA	0.804	0.481
MBC	**0.896**	0.211
LC	**0.883**	0.083
BD	**-0.882**	0.171
MWD	**0.908**	0.067

Table 138: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs								
PC1	OC	P	K	Zn	MBC	LC	BD	MWD
OC	1.00	0.867**	0.797**	0.656**	0.626*	0.677**	-0.712**	0.696**
P	0.867**	1.00	0.788**	0.685**	0.617*	0.693**	-0.758**	0.710**
K	0.797**	0.788**	1.00	0.616*	0.771**	0.760**	-0.762**	0.842**
Zn	0.656**	0.685**	0.616*	1.00	0.219	0.493	-0.552*	0.314
MBC	0.626*	0.617*	0.771**	0.219	1.00	0.803**	-0.762**	0.937**
LC	0.677**	0.693**	0.760**	0.493	0.803**	1.00	-0.782**	0.747**
BD	-0.712**	-0.758**	-0.762**	-0.552*	-0.762**	-0.782**	1.00	-0.700**
MWD	0.696**	0.710**	0.842**	0.314	0.937**	0.747**	-0.700**	1.00
PC2	N	Fe						
N	1.00	0.655**						
Fe	0.655**	1.00						
Correlation sum	1.655	1.655						

*correlation is significant at P = 0.05 level; **correlation is significant at P = 0.01 level

4.2.31.3. Soil quality indices

The key indicators viz., organic carbon, available N, available P, available K, available Fe & Zn, microbial biomass carbon, bulk density and mean weight diameter which were retained in the final MDS were use to compute the soil quality indices for the maize-wheat rotation system in Inceptisols of Rakhdhiansar. The nutrient management treatments significantly influenced the soil quality indices and varied between 3.69 to 5.66 across the management treatments while the relative soil quality indices varied between 0.63 to 0.96 (Table 139 & Fig 117). Of all the nutrient management treatments, application of FYM @ 10 t ha^{-1} + 40 kg N ha^{-1} maintained significantly highest SQI of 5.66 which was at par with application of FYM @ 10 t ha^{-1} + 30 kg N ha^{-1} and green manuring with Sunhemp + 20 kg N ha^{-1} both of which maintained SQI of 5.40. Irrespective of their statistical significance, the relative order of performance of the nutrient management treatments in maintaining the soil quality indices were: T4: FYM @ 10 t ha^{-1} + 40 kg N ha^{-1} (5.66) > T5: Green manuring with Sunhemp + 20 kg N ha^{-1} (5.44) > T3: FYM @ 10 t ha^{-1} + 30 kg N ha^{-1} (5.40) = > T2: FYM @ 10 t ha^{-1} + 20 kg N ha^{-1} (5.16) > T1: Control (3.69). The percent contributions of each of these key indicators towards soil quality indices were also computed. It was observed that almost all the key indicators contributed more or less equally towards the soil quality indices except available N and available Fe, which contributed to a minimum extent of 2.27 % and 1.90% respectively. The percent contribution of the other key indicators was as follows: organic carbon (13.8%), available P (13.4%), available K (14.5%), available

Zn (12.6%), microbial biomass carbon (13.7%), bulk density (16.2%) and mean weight diameter (11.6%) (Fig 118).

Table 139: Soil quality indices (SQI) and relative soil quality indices (RSQI) as influenced by different nutrient management treatments under maize-wheat rotation system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	SQI	RSQI
1	T1: Control	3.69	0.63
2	T2: FYM @ 10 t ha^{-1} + 20 kg N ha^{-1}	5.16	0.88
3	T3: FYM @ 10 t ha^{-1} + 30 kg N ha^{-1}	5.40	0.92
4	T4: FYM @ 10 t ha^{-1} + 40 kg N ha^{-1}	5.66	0.96
5	T5: Green manuring with Sunhemp + 20 kg N ha^{-1}	5.44	0.92
	CD @ 0.05	0.65	0.11

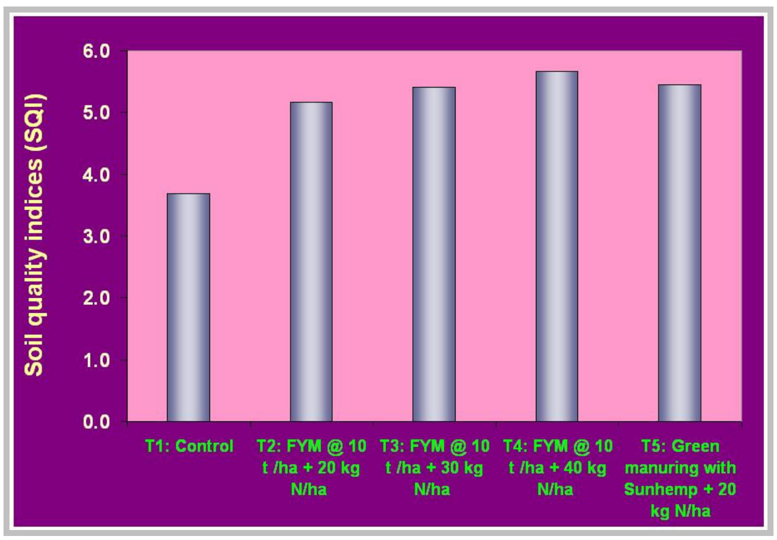


Fig 117: Soil quality indices (SQI) as influenced by different nutrient management treatments under maize-wheat rotation system in Inceptisols of Rakhdhiansar

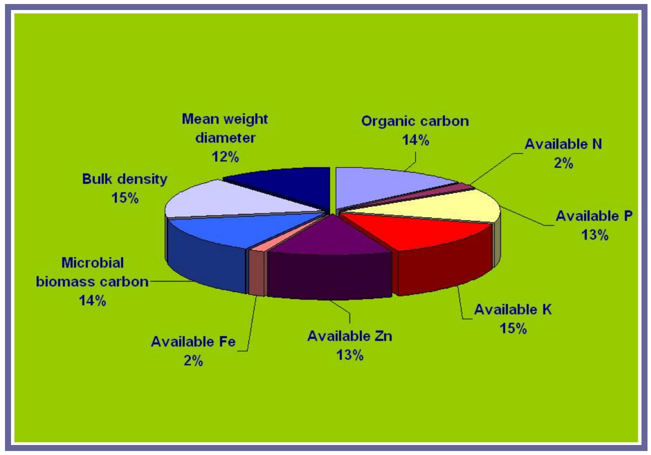


Fig 118: Percent contribution of key indicators towards soil quality indices (RSQI) as influenced by different nutrient management treatments under maize-wheat rotation system in Inceptisols of Rakhdhiansar

4.2.32. Experiment 4: Tillage and nutrient management for resource conservation and improving soil quality

Successful cultivation practices in general involve intensive tillage of land, which consumes major portion of cost/energy. Low tilled conservation farming strategy is aimed to reduce the tillage input for better resource conservation including energy. If low till/ plough in field is practiced for longer period and the crop residues are recycled, the soil ecology will build up to such an extent that the adverse effect of low till will be minimized. The crop stubbles and organic residues like leuceana besides improving the soil organic matter status should also help in moisture conservation and improving water intake. Hence, in order to quantify the energy savings with low till systems, to work out the appropriate practices for the success of minimum till system, and to assess the impact of low till system and nutrient management on crop yield and soil quality, an experiment was initiated during 2002 in a split plot design with three main and three sub-treatments using maize (Kanchan-510) as test crop. The three main treatments included: T1: conventional tillage (CT) + interculture, T2: 50% CT + interculture and T3: 50% CT + weedicide + interculture. The three sub treatments included T1: 100% N through organic sources, T2: 50% N through organic sources + 50 % N through inorganic sources and T3: 100% N through inorganic sources. Studies were taken up in this experimental site during the year 2005 after fourth year of experimentation to assess the influence of tillage and nutrient management practices on soil quality.

Data revealed that, the soil reaction of the experimental plots was slightly acidic ranging from 6.02 to 6.54 and was not significantly influenced by any of the soil and nutrient management treatments (Table 140). Similar to soil pH, EC was also not influenced by any of the management practices and ranged between 0.05 to 0.08 dS m^{-1}. Organic carbon was observed to be low in these soils ranging from 4.17 to 5.25 g kg^{-1}. Tillage did not show any significant influence on soil organic carbon but the nutrient management treatments showed a significant influence where the application of nitrogen through 100% organic sources recorded the highest organic carbon content of 4.92 g kg^{-1} followed by the application of 100% inorganic sources. Among the macronutrients, the treatments showed a similar influence on available N and P where only the nutrient management treatments showed a significant influence while tillage did not. Available N was found to be very low in these soils and varied from 140.5 to 161.3 kg ha^{-1} across the treatments while available P varied from 20.5 to 32.1 kg ha^{-1} and was found to be high. Among the nutrient management practices, on an average, application of nutrients through inorganic sources recorded significantly highest available N (159.8 kg ha^{-1}) and P

(30.9 kg ha^{-1}). In case of available K, neither tillage nor the nutrient management treatments made any significant influence and it varied from 186.9 to 212.4 kg ha^{-1} across the management treatments (Fig 119).

Table 140: Effect of different tillage and nutrient management treatments on physico-chemical and chemical soil quality parameters under maize cropping system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	pH	EC dS m^{-1}	OC (g kg^{-1})	N	P	K
					(kg ha^{-1})		
1	CT + IC + 100% N (organic)	6.12	0.06	4.63	149.1	25.1	188.3
2	CT + IC + 50% N (organic) + 50 % inorganic)	6.02	0.05	4.17	145.9	22.8	186.9
3	CT + IC + 100% N (inorganic)	5.93	0.06	4.67	160.1	31.2	212.4
4	50% CT + IC + 100% N (organic)	6.14	0.05	4.87	155.7	24.8	187.7
5	50% CT + IC + 50% N (organic) + 50 % inorganic)	6.04	0.07	4.30	150.1	22.1	192.2
6	50% CT + IC + 100% N (inorganic)	6.23	0.06	4.53	157.6	32.1	205.6
7	50% CT + Weedicide + One IC + 100% N (organic source/compost)	6.54	0.07	5.25	140.5	20.5	197.3
8	50% CT + Weedicide + One IC + 50% N (organic) + 50 % inorganic source)	6.48	0.07	4.52	146.3	25.3	205.3
9	50% CT + Weedicide + One IC + 100% N (inorganic source)	6.47	0.08	4.55	161.3	29.6	198.8
	CD @ 0.05						
	Between two main treatment means	NS	NS	NS	NS	NS	NS
	Between two sub treatment means	NS	NS	0.38	10.6	4.65	NS
	Between two sub treatment means at same main treatments	NS	NS	NS	NS	NS	NS
	Between two main treatment means at same or different sub treatments	NS	NS	NS	NS	NS	NS

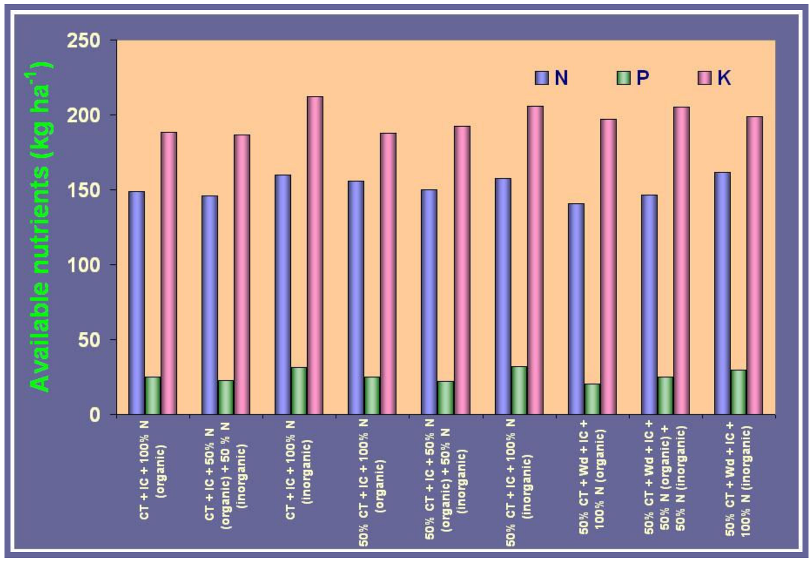


Fig 119: Effect of different tillage and nutrient management treatments on chemical soil quality parameters under maize cropping system in Inceptisols of Rakhdhiansar

Among the secondary nutrients, the tillage and nutrient management treatments did not show any significant influence on exchangeable Ca and Mg and varied from 2.00 to 3.18 and 0.55 to 0.73 c mol kg^{-1} respectively across the management treatments (Table 141 & Fig 120). But available S, varying from 16.2 to 23.4 kg ha^{-1} was significantly influenced by both tillage and nutrient management treatments. Among the tillage practices, on an average, practice of conventional tillage + one interculture operation recorded the highest available S of 20.8 kg ha^{-1} while among the nutrient management treatments, application of nutrient through organic sources showed the highest available S (21.9 kg ha^{-1}). Among the micronutrients, available Fe and Mn were not influenced by any of the management treatments and varied from 10.6 to 13.8 μg g^{-1} and 11.7 to 14.9 μg g^{-1} across the management treatments. But available Zn and Cu varying from 1.18 to 1.87 μg g^{-1} and 0.45 to 0.59 μg g^{-1} across the management treatments were also not significantly influenced by tillage and nutrient management treatments but were influenced only by their interaction effects. Tillage did not significantly influence the available B content but the nutrient management treatments showed a significant influence, where application of 100% organic sources recorded the highest available B content (0.65 μg g^{-1}) (Fig 121).

Table 141: Effect of different tillage and nutrient management treatments on chemical soil quality parameters (secondary and micronutrients) under maize cropping system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		cmol kg^{-1}		(kg ha^{-1})	$\mu g\ g^{-1}$				
1	CT + Two IC + 100% N (organic source/compost)	2.76	0.72	23.4	1.32	10.6	0.50	14.1	0.63
2	CT + Two IC + 50% N (organic) + 50 % inorganic source)	2.57	0.68	20.3	1.25	12.8	0.55	14.5	0.54
3	CT + two IC + 100% N (inorganic source)	2.00	0.56	18.9	1.61	13.8	0.55	14.0	0.47
4	LT + Two IC + 100% N (organic source/compost)	2.41	0.59	20.5	1.62	11.5	0.45	11.7	0.64
5	LT + Two IC + 50% N (organic) + 50 % inorganic source)	2.57	0.56	16.6	1.87	12.9	0.53	14.4	0.58
6	LT + IC + 100% N (inorganic source)	2.85	0.64	17.7	1.20	11.9	0.59	14.9	0.48
7	LT + Weedicide + One IC + 100% N (organic source/compost)	2.82	0.73	21.9	1.19	12.0	0.59	13.8	0.68
8	LT + Weedicide + One IC + 50% N (organic) + 50 % inorganic source)	2.93	0.55	17.5	1.18	12.3	0.47	12.2	0.66
9	LT + Weedicide + One IC + 100% N (inorganic source)	3.18	0.60	16.2	1.39	13.3	0.59	14.9	0.53
	CD @ 0.05								
	Between two main treatment means	NS	NS	2.00	NS	NS	NS	NS	NS
	Between two sub treatment means	NS	NS	1.72	NS	NS	NS	NS	0.07
	Between two sub treatment means at same main treatments	NS	NS	NS	0.37	NS	0.10	NS	NS
	Between two main treatment means at same or different sub treatments	NS	NS	NS	0.41	NS	0.09	NS	NS

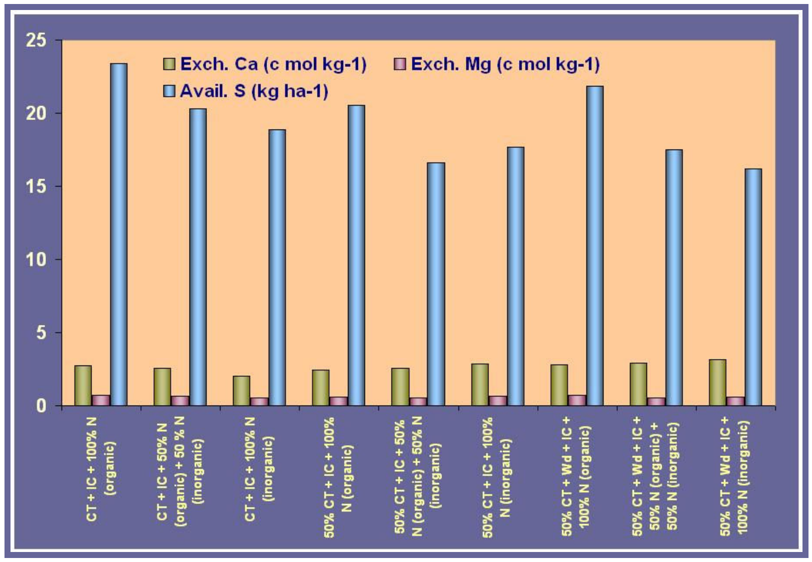


Fig 120: Effect of different tillage and nutrient management treatments on chemical soil quality parameters (secondary nutrients) under maize cropping system in Inceptisols of Rakhdhiansar

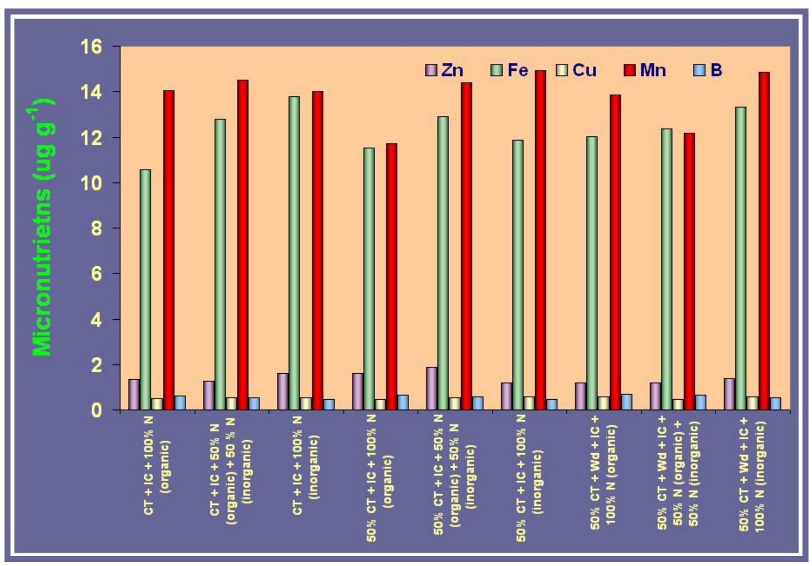


Fig 121: Effect of different tillage and nutrient management treatments on chemical soil quality parameters (micronutrients) under maize cropping system in Inceptisols of Rakhdhiansar

Among the biological soil quality parameters, the significant influence of tillage was observed only on microbial biomass carbon, while the nutrient management treatments showed a significant influence on both dehydrogenase activity and labile carbon (Table 142 & Fig 122). The interaction effects of tillage as well as the nutrient management treatments did not have any significant influence on any of the biological soil quality parameters. However, dehydrogenase activity varied from 1.47 to 2.43 μg TPF $hr^{-1}g^{-1}$, microbial biomass carbon from 161.2 to 193.1 μg g^{-1} of soil and labile carbon from 268.1 to 324.5 μg g^{-1} of soil across the management treatments. On an average, among the tillage practices, the practice of conventional tillage + one interculture operation showed highest microbial biomass carbon of 181.0 μg g^{-1} of soil while among the nutrient management practices, the application of nutrients through 100% organic sources significantly influenced the dehydrogenase activity (2.23 μg TPF $hr^{-1}g^{-1}$) and labile carbon (311.7 μg g^{-1} of soil). Bulk density of these soils varied from 1.34 to 1.61 Mg m^{-3} while the mean weight diameter of the soil aggregates varied from 0.16 to 0.25 mm across the management treatments. The practice of 50% conventional tillage + weedicide + one interculture operation maintained significantly highest mean weight diameter (0.21 mm) while the bulk density was not influenced by any of the tillage practices. Among the nutrient management practices, application of nutrients through 100% organic sources recorded significantly highest mean weight diameter of 0.23 mm while the conjunctive application of nutrients significantly influenced the bulk density (1.47 Mg m^{-3}) (Fig 123).

Table 142: Effect of different tillage and nutrient management treatments on biological and physical soil quality parameters under maize cropping system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	DHA (μg TPF $hr^{-1}g^{-1}$)	MBC (μg g^{-1} of soil)	LC (μg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	CT + Two IC + 100% N (organic source/compost)	2.10	188.4	294.5	1.50	0.17
2	CT + Two IC + 50% N (organic) + 50 % inorganic source)	1.66	185.7	275.2	1.34	0.16
3	CT + Two IC + 100% N (inorganic source)	1.71	187.3	278.3	1.58	0.16
4	LT + Two IC + 100% N (organic source/compost)	2.16	193.1	316.2	1.50	0.25
5	LT + Two IC + 50% N (organic) + 50 % inorganic source)	1.91	185.3	268.1	1.56	0.18
6	LT + IC + 100% N (inorganic source)	1.47	179.2	278.7	1.61	0.19
7	LT + Weedicide + One IC + 100% N (organic source/compost)	2.43	161.2	324.5	1.50	0.25
8	LT + Weedicide + One IC + 50% N (organic) + 50 % inorganic source)	1.97	162.1	296.7	1.50	0.20
9	LT + Weedicide + One IC + 100% N (inorganic source)	1.86	173.3	285.5	1.54	0.18
	CD @ 0.05					

SNo	Name of the treatments	DHA (µg TPF $hr^{-1}g^{-1}$)	MBC (µg g^{-1} of soil)	LC (µg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
	Between two main treatment means	NS	12.8	NS	NS	0.02
	Between two sub treatment means	0.26	NS	19.8	0.06	0.02
	Between two sub treatment means at same main treatments	NS	NS	NS	0.10	0.03
	Between two main treatment means at same or different sub treatments	NS	NS	NS	0.12	0.03

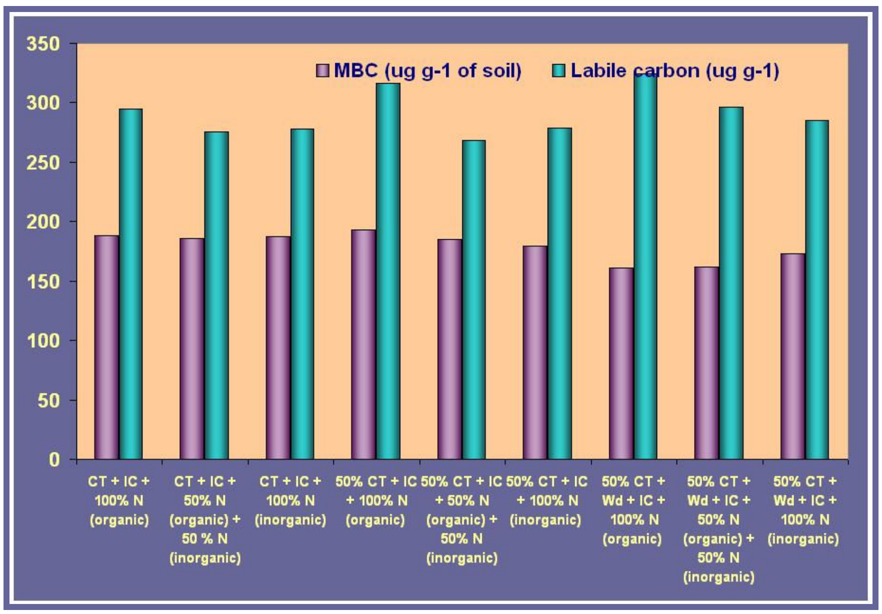


Fig 122: Effect of different tillage and nutrient management treatments on biological soil quality parameters under maize cropping system in Inceptisols of Rakhdhiansar

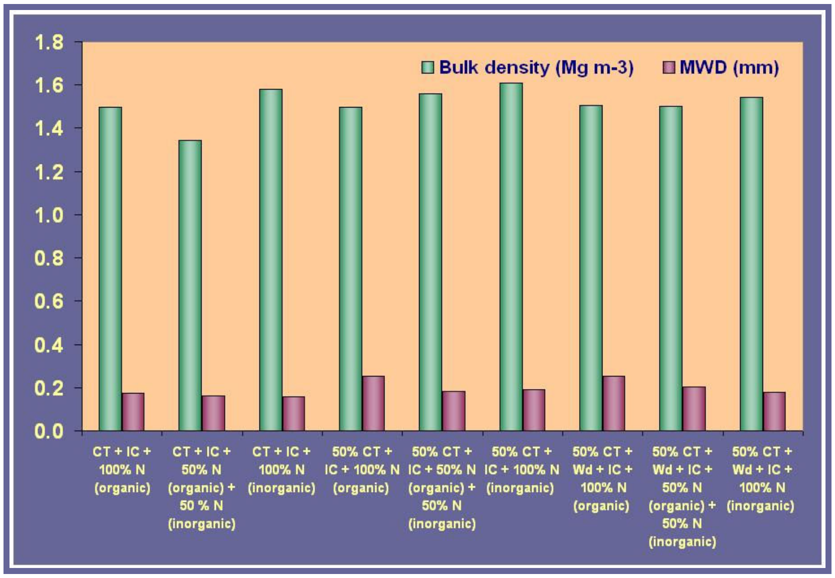


Fig 123: Effect of different tillage and nutrient management treatments on physical soil quality parameters under maize cropping system in Inceptisols of Rakhdhiansar

4.2.32.1. Key indicators and soil quality assessment

4.2.32.2. Results of Principal Component Analysis

The influence of tillage and nutrient management treatments practiced under maize cropping system on 19 soil quality parameters were studied. The statistical analysis of these parameters revealed that out of these 19 soil quality parameters, 7 parameters viz., pH, EC, available K, exchangeable Ca & Mg, and available Fe & Mn were not significant and hence were not included for further PCA analysis. The other 12 parameters, which showed significance with either the main treatment or their interaction effects, were considered for the P144C analysis. The PC analysis carried out with 12 significant variables gave four PCs which had eigen values > 1 and explaining about 67.9% variance in the data set (Table 143). Out of the four PCs, PC1 had three variables viz., available B, labile carbon and mean weight diameter emerged as the highly weighted variables while in PC2, PC3 and PC4, only single variables viz., available P, available Zn and available S, respectively, were found to be highly weighted. The correlation matrix run for the variables under PC1 revealed insignificant relation between the parameters and hence all the parameters under PC1 were considered for the final MDS (Table 144). Hence, the six indicators retained for the final MDS included available P, available

S, available Zn & B, labile carbon and mean weight diameter and were termed as the key indicators for maize cropping system in Inceptisols of Rakhdhiansar.

Table 143: Principal component analysis of soil quality parameters as influenced by tillage and nutrient management treatments under maize cropping system in Inceptisols of Rakhdhiansar

	PC1	PC2	PC3	PC4
Total Eigen values	3.629	1.855	1.507	1.155
% of Variance	30.240	15.462	12.557	9.625
Cumulative %	30.240	47.702	58.259	67.884
Eigen Vectors				
OC	0.470	0.556	0.374	-0.007
N	-0.465	0.415	0.241	0.203
P	-0.464	0.647	-0.010	0.176
S	0.596	-0.031	0.110	0.657
Zn	-0.316	-0.361	0.667	-0.254
Cu	-0.188	0.327	-0.599	-0.279
B	0.813	-0.074	-0.090	-0.193
DHA	0.728	-0.263	0.306	-0.300
MBC	-0.315	-0.123	0.409	0.415
LC	0.737	0.413	-0.109	0.142
BD	-0.330	0.550	0.407	-0.421
MWD	0.737	0.393	0.214	-0.111

Table 144: Pearson's Correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs			
PC1	B	LC	MWD
B	1.00	0.649**	0.496**
LC	0.649**	1.00	0.649**
MWD	0.496**	0.649**	1.00
Correlation sum	2.145	2.298	2.145

*correlation is significant at P = 0.05 level
**correlation is significant at P = 0.01 level

4.2.32.3. Soil quality indices

Soil quality indices were computed using the six key indicators retained in the final MDS viz., available P, available S, available Zn & B, labile carbon and mean weight diameter. The statistical analysis revealed that the tillage treatments did not show any significant influence in improving the soil quality while the nutrient management treatments played a significant role in maintaining the soil quality. The soil quality indices varied between 1.28 to 1.58 while the relative soil quality indices varied between 0.79 to 0.97 across the management treatments (Table 145 & Fig 124). Among the nutrient management treatments, application of 100% N through organic sources maintained significantly highest soil quality (1.52) followed by application of 50% N through organic sources + 50 % N through inorganic sources (1.36) which was at par with the application of 100% N through inorganic sources (1.33). The percent contribution of these key indicators towards soil quality indices was as follows: available P (11.0%), available S (7.23%), available Zn (8.99%), available B (23.3%), labile carbon (26.6%) and mean weight diameter (22.9%) (Fig 125).

Table 145: Soil quality indices (SQI) and relative soil quality indices (RSQI) as influenced by different tillage and nutrient management treatments under maize cropping system in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	SQI	RSQI
1	CT + Two IC + 100% N (organic source/compost)	1.41	0.87
2	CT + Two IC + 50% N (organic) + 50 % (inorganic source)	1.28	0.79
3	CT + Two IC + 100% N (inorganic source)	1.31	0.81
4	LT + Two IC + 100% N (organic source/compost)	1.58	0.97
5	LT + Two IC + 50% N (organic) + 50 % (inorganic source)	1.36	0.84
6	LT + IC + 100% N (inorganic source)	1.33	0.82
7	LT + Weedicide + One IC + 100% N (organic source/compost)	1.56	0.96
8	LT + Weedicide + One IC + 50% N (organic) + 50 % (inorganic source)	1.44	0.89
9	LT + Weedicide + One IC + 100% N (inorganic source)	1.35	0.83
	CD @ 0.05		
	Between two main treatment means	NS	NS
	Between two sub treatment means	**	**
	Between two sub treatment means at same main treatments	NS	NS
	Between two main treatment means at same or different sub treatments	NS	NS

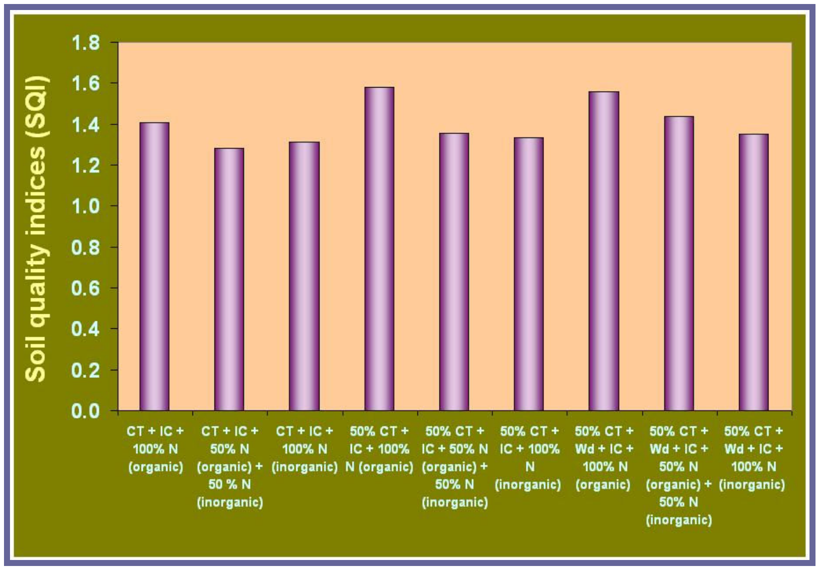


Fig 124: Soil quality indices (SQI) as influenced by different tillage and nutrient management treatments under maize cropping system in Inceptisols of Rakhdhiansar

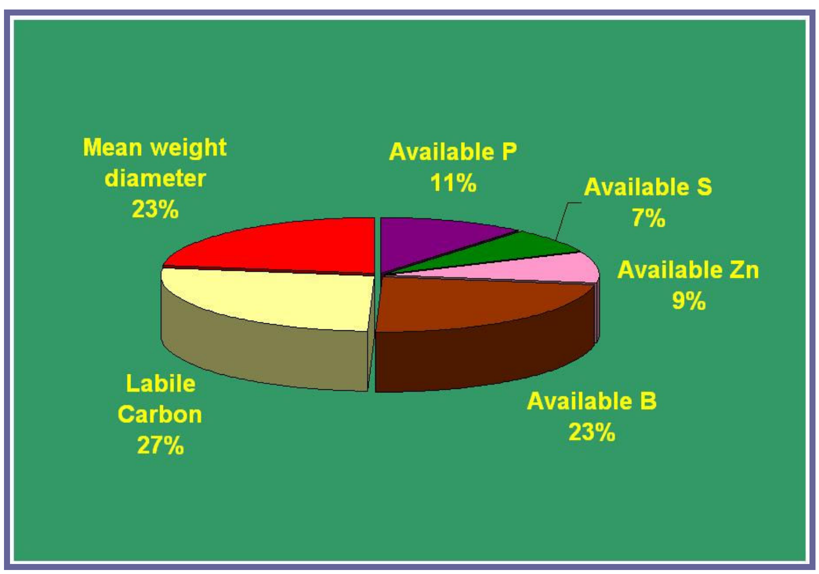


Fig 125: Percent contribution of key soil quality indicators towards soil quality indices (RSQI) as influenced by different tillage and nutrient management treatments under maize cropping system in Inceptisols of Rakhdhiansar

4.2.33. Experiment 5: Farmer's fields

The cropping systems practiced in farmer's fields when statistically tested for their influence on soil quality parameters proved insignificant for almost all the parameters except for dehydrogenase activity as well as microbial biomass carbon. However, soils under these cropping systems were near neutral to neutral in reaction with EC ranging from 0.18 to 0.21 dS m^{-1} (Table 146). Organic carbon was observed to be low in these cropping systems varying from 3.90 to 4.11 g kg^{-1}. Among the macronutrients, available N was very low in these soils (142.2 to 167.2 kg ha^{-1}) while available P and K were high and medium with values ranging from 24.8 to 35.2 kg ha^{-1} and 249.0 to 283 kg ha^{-1} respectively across the cropping systems.

Table 146: Influence of different cropping systems on physico-chemical and chemical soil quality parameters practiced under farmers fields in Inceptisols of Rakhdhiansar

SNo	Name of the cropping systems	pH	EC dS m^{-1}	OC (g kg^{-1})	N	P	K
					(kg ha^{-1})		
1	Maize- Wheat	6.96	0.21	3.97	150.1	35.2	249.0
2	Pearl millet - Wheat	6.99	0.21	3.99	146.3	34.6	283.4
3	Black gram - Wheat	6.80	0.19	3.90	167.2	31.1	251.7
4	Wheat + Chick pea	7.02	0.18	3.92	157.9	27.3	269.7
5	Maize- Toria - Wheat	6.92	0.19	4.11	142.2	30.0	262.0
6	Maize - Chickpea	6.97	0.18	3.59	153.4	24.8	262.7
	CD @ 0.05	NS	NS	NS	NS	NS	NS

Exchangeable Ca and Mg were found to be adequate ranging from 3.68 to 4.69 cmol kg^{-1} and 0.69 to 0.98 cmol kg^{-1} respectively across the various cropping systems (Table 147). Available S was medium to high in these soils ranging from 14.3 to 18.0 kg ha^{-1}. Among the micronutrients, all the micronutrients viz., Zn, Fe Mn and B were observed to be high in these soils ranging from 1.17 to 1.34, 9.50 to 11.7, 12.5 to 14.7 and 0.73 to 0.88 μg g^{-1} respectively while Cu was medium (0.53 to 0.67 μg g^{-1}) across the different cropping systems under farmers fields.

Table 147: Influence of different cropping systems on chemical soil quality parameters practiced under farmers fields in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	Ca	Mg	S	Zn	Fe	Cu	Mn	B
		cmol kg^{-1}		(kg ha^{-1})	µg g^{-1}				
1	Maize- Wheat	4.21	0.73	17.6	1.29	10.7	0.67	13.8	0.88
2	Pearl millet - Wheat	4.47	0.96	16.5	1.27	9.50	0.59	14.6	0.88
3	Black gram - Wheat	4.69	0.98	14.3	1.17	10.7	0.56	12.5	0.86
4	Wheat + Chick pea	4.10	0.77	16.8	1.25	10.4	0.60	13.8	0.77
5	Maize- Toria - Wheat	3.87	0.74	18.0	1.34	11.7	0.53	14.6	0.77
6	Maize - Chickpea	3.68	0.69	15.7	1.24	11.2	0.63	14.7	0.73
	CD @ 0.05	NS	NS	NS	NS	NS	NS	NS	NS

Among the biological soil quality parameters, dehydrogenase activity as well as microbial biomass carbon was significantly influenced by the cropping systems practiced while labile carbon content was not conspicuously influenced (Table 148). Dehydrogenase activity varied from 2.75 to 4.69 µg TPF hr^{-1}g^{-1} across the cropping systems and significantly highest DHA was recorded under blackgram- wheat system (4.69 µg TPF hr^{-1}g^{-1}) followed by Maize-Wheat system (3.94 µg TPF hr^{-1}g^{-1}) while maize-toria-wheat system recorded the lowest (2.75 µg TPF hr^{-1}g^{-1}). Microbial biomass carbon was significantly highest under pearl millet-wheat system (206.6 µg g^{-1} of soil), which was at par with maize-toria-wheat system (199.9 µg g^{-1} of soil). Labile carbon varied between 323.7 to 360.7 µg g^{-1} of soil across the cropping systems and was not significantly influenced. Bulk density of the soils under these cropping systems ranged from 1.40 to 1.45 Mg m^{-3} with a mean weight diameter of 0.22 to 0.29 mm and were not influenced by the cropping systems.

Table 148: Influence of different cropping systems on biological and physical soil quality parameters practiced under farmers fields in Inceptisols of Rakhdhiansar

SNo	Name of the treatments	DHA (µg TPF hr^{-1}g^{-1})	MBC (µg g^{-1} of soil)	LC (µg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
1	Maize- Wheat	3.94	156.3	336.1	1.45	0.24
2	Pearl millet - Wheat	3.59	206.6	323.7	1.42	0.25
3	Black gram - Wheat	4.69	188.2	360.7	1.44	0.27
4	Wheat + Chick pea	3.74	172.6	342.8	1.45	0.29
5	Maize- Toria - Wheat	2.75	199.9	339.1	1.40	0.22
6	Maize - Chickpea	3.83	153.3	345.7	1.43	0.23
	CD @ 0.05	*	**	NS	NS	NS

4.2.33.1. Computation of soil quality indices

As majority of the soil quality indicators studied in farmer's fields were not significantly influenced by the cropping systems, soil quality indices could not be computed.

Table 149: Summary of soil quality indices and relative soil quality indices as influenced by different soil nutrient management practices under different trials practiced in Inceptisols of Rakhdhiansar

Sno		SQI	RSQI
Experiment 1: Integrated nutrient supply system for rainfed semi-arid tropics			
1	T1: Control	2.68	0.63
2	T2: 100 % N (inorganic)	3.55	0.83
3	T3: 50 % N (inorganic)	3.46	0.81
4	T4: 25 kg N (compost)	4.17	0.97
5	T5: 15 kg N (compost) + 10 kg N (inorganic)	3.75	0.87
6	T6: 15 kg N (compost) + 20 kg N (inorganic)	4.05	0.94
Experiment 2: Permanent manurial trial			
1	T1: Control	0.97	0.62
2	T2: 100% NPK (60:40:20 kg ha^{-1})	1.38	0.89
3	T3: 50% NPK	1.33	0.85
4	T4: 50%N (crop residue)	1.25	0.80
5	T5: 50%N (FYM)	1.52	0.98
6	T6: 50% NPK + 50% N (Crop residue)	1.46	0.94
7	T7: 50% NPK + 50% N (FYM)	1.52	0.97
Experiment 3: Nutrient management in maize- wheat rotation			
1	T1: Control	3.69	0.63
2	T2: FYM @ 10 t ha^{-1} + 20 kg N ha^{-1}	5.16	0.88
3	T3: FYM @ 10 t ha^{-1} + 30 kg N ha^{-1}	5.40	0.92
4	T4: FYM @ 10 t ha^{-1} + 40 kg N ha^{-1}	5.66	0.96
5	T5: Green manuring with Sunhemp + 20 kg N ha^{-1}	5.44	0.92
Experiment 4: Tillage and nutrient management for resource conservation and improving soil quality.			
1	CT + Two IC + 100% N (organic source/compost)	1.41	0.87
2	CT + Two IC + 50% N (organic) + 50 % (inorganic source)	1.28	0.79

Sno		SQI	RSQI
3	CT + Two IC + 100% N (inorganic source)	1.31	0.81
4	LT + Two IC + 100% N (organic source/compost)	1.58	0.97
5	LT + Two IC + 50% N (organic) + 50 % (inorganic source)	1.36	0.84
6	LT + IC + 100% N (inorganic source)	1.33	0.82
7	LT + Weedicide + One IC + 100% N (organic source/compost)	1.56	0.96
8	LT + Weedicide + One IC + 50% N (organic) + 50 % (inorganic source)	1.44	0.89
9	LT + Weedicide + One IC + 100% N (inorganic source)	1.35	0.83
Experiment 5: Farmers Fields			
1	Maize- Wheat	--	--
2	Pearl millet - Wheat	--	--
3	Black gram - Wheat	--	--
4	Wheat + Chick pea	--	--
5	Maize- Toria - Wheat	--	--
6	Maize - Chickpea	--	--

Table 150: Summary of key soil quality indicators, soil quality indices and the best soil nutrient management practices identified under different cropping systems in Inceptisols of Rakhdhiansar

Sno	Key soil quality indicators and their % contribution	SQI	RSQI	Best management practices with higher SQI
Experiment 1: Integrated nutrient supply system for rainfed semi-arid tropics				
	• Available N (3.49%) • Exchangeable Ca (19.6%) • Available Zn (16.6%) • Available B (19.3%) • Microbial biomass carbon (19.7%) • Bulk density (21.4%)	2.68 – 4.17	0.63 – 0.97	1. Application of 25 kg N (compost) (4.17) 2. Application of 15 kg N (compost) + 20 kg N (inorganic) (4.05)
Experiment 2: Permanent manurial trial				
	• pH (8.05%) • EC (6.01%) • Organic carbon (4.87%) • Available P (4.45%) • Available S (31.9 %)	0.97 – 1.52	0.62 – 0.98	1. Application of 50%N (FYM) (0.98) 2. Application of 50% NPK + 50% N (FYM) (0.97) 3. Application of 50% NPK + 50% N (Crop residue) (0.94)

Sno	Key soil quality indicators and their % contribution	SQI	RSQI	Best management practices with higher SQI
	• Available Zn (4.56%) • Dehydrogenase assay (8.36%) • Microbial biomass carbon (31.8%)			
Experiment 3: Nutrient management in maize- wheat rotation				
	• Organic carbon (13.8%) • Available P (13.4%) • Available K (14.5%) • Available Zn (12.6%) • Microbial biomass carbon (13.7%) • Bulk density (16.2%) • Mean weight diameter (11.6%) • Available N (2.27 %) • Available Fe (1.90%)	3.69 – 5.66	0.63 – 0.96	1. Application of FYM @ 10 t ha^{-1} + 40 kg N ha^{-1} (5.66) 2. Application of green manuring with Sunhemp + 20 kg N ha^{-1} (5.44) 3. Application of FYM @ 10 t ha^{-1} + 30 kg N ha^{-1} (5.40)
Experiment 4: Tillage and nutrient management for resource conservation and improving soil quality				
	• Available P (11.0%) • Available S (7.23%) • Available Zn (8.99%) • Available B (23.3%) • Labile carbon (26.6%) • Mean weight diameter (22.9%)	1.28 – 1.58	0.79 – 0.97	1. Application of 100% N through organic sources (1.52) 2. Application of 50% N through organic sources + 50 % N through inorganic sources (1.36) 3. Application of 100% N through inorganic sources (1.33).
Experiment 5: Farmers fields				
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4.2.34. Assessment of chemical soil quality in rainfed farmer's fields in Ranga Reddy District of Andhra Pradesh and issuing of soil health report

There have been concerns that despite having more than 600 soil testing labs in the country, the soil health assessment program is not very effective. In few cases, the tests have been limited only up to organic C, P and K and recommendations are made only on macro basis without considering the soil health status of individual farmer holdings. In order to get optimum out put from every unit of input used from precious soil resource and to maintain its functional capacity for future use, it is absolutely necessary to develop a method of assessment and monitoring of soil health and trekking it periodically. In the countries, where the farmers are literate, can take care of soil health on their own or by referring the soil health cards given to them by government or soil care agencies. However, under Indian conditions, where majority of the farming community is illiterate, a structured mechanism of periodical assessing and monitoring the soil quality has to be developed. Study was initiated with the objective to assess soil quality in rainfed farmer's fields and develop soil chemical quality index in collaboration with Krishi Vigyan Kendra (KVK) of this Institute under Frontline Demonstration experiments on Maize. Soil samples collected by KVK centre from 338 rainfed farmer's fields representing two mandals (Shabad and Kandukur) covering 8 villages (Bobbligum, Pulimamidi, Moddemguda, Pochammathanda, Pulimamidi, Saireddyguda, Saralaraopalli and Thandamucherla) of Rangareddy district predominantly representing two soil types (Black and red) were analyzed for 13 soil chemical health indicators (pH, EC, OC, available N, P, K, exchangeable Ca, Mg, DTPA extractable Zn, Fe, Cu, Mn and DTPA-sorbitol extractable boron). The results were processed and a computer generated soil chemical health test reports with specific indications and suggestions were prepared with the help of other associated Scientist and programmer of the institute and issued to KVK section for distribution to the farmers. A sample of computer generated soil chemical health report is appended (Chart 1).

4.2.35. Objective 2: To evaluate the low-cost integrated nutrient management (INM) treatments (comprising of farm based organics) under conventional and reduced tillage in sorghum-mung bean strip cropping system in Alfisol

Rainfed Alfisols encounter diversity of constraints on account of physical, chemical and biological soil health viz., shallow soil depth, low clay content, poor aggregation and poor soil structure, compaction and crusting and higher soil strength, low water retention capacity, low organic C, low fertility status and low CEC. At the sub-surface, soils are characterized by gleying and murrum layer comprising of disintegrated hard rock mass and clay dominated by hydrous oxides of iron and Aluminum. Farmers of the region are also poor and cannot afford fertilizers. In order to get desired productivity from these lands, it is of paramount importance to improve the functional capacity (Soil Quality) of these soils by way of balanced nutrition through integrated nutrient management and by improving organic C status of these soils by way of using organics and following reduce tillage approach. Enhancing organic matter under tropical conditions becomes utmost difficult. Therefore, it was absolutely necessary to focus the efforts on enhancing organic matter in soil at all costs through conservation tillage, integrated nutrient management and incorporation of legumes in the cropping systems.

4.2.35.1. Technical Programme and results

A long-term experiment was initiated during 1998 with sorghum (SPV 1616) and mung bean (cv ML-267) as test crops at Hayathnagar Research Farm of Central Research Institute for Dryland Agriculture, Hyderabad. The main objective of the study was to identify effective Integrated Nutrient Management (INM) treatments, enhance organic matter and improve soil quality. The experiment was conducted in a strip plot design with two tillages: conventional (CT) and reduced (RT) and five INM treatments: Control (T_1), 40 kg N through urea (T_2), 4 t compost + 20 kg N (T_3), 2 t Gliricidia loppings + 20 kg N (T_4) and 4 t compost + 2 t Gliricidia loppings (T_5) for sorghum crop to supply N equivalent to 40 kg N ha^{-1}. For mung bean crop, the same treatments were adjusted to supply nitrogen equivalent to 20 kg N ha^{-1} and were as follows: Control (no nitrogen) (T_1), 20 kg N through urea (T_2), 2 t compost + 10 kg N (T_3), 1 t Gliricidia loppings + 10 kg N (T_4) and 2 t compost + 1 t Gliricidia loppings (T_5). Recommended level of phosphorus was applied equally to both sorghum and mung bean crops uniformly. The responses of sorghum (CSH 5/ CSH 6) and mung bean crop (ML 267) to tillage and INM treatments were studied and the results are presented under the following heads.

4.2.35.2. Sorghum grain yields as influenced by low cost integrated nutrient management and tillage practices under sorghum- green gram strip cropping system

An on going experiment which was started during 1998 was adopted for the study. During the period of this report also field experiment were conducted. Pooled analysis of grain yield data of sorghum as influenced by tillage and INM treatments was done for a period of ten years and the data is presented in Table 151 & Fig 126 to 128. Over ten years of experimentation, it was observed that both tillage as well as the nutrient management treatments showed a significant influence on sorghum grain yields. Out of these ten years period, significantly highest sorghum grain yields were observed during the year 2002 (1929 kg ha^{-1}) followed by the year 2004 (1682 kg ha^{-1}) while the lowest yields were observed during the year 2005 (1165.3 kg ha^{-1}). On an average, over the years as well as the treatments, conventional tillage performed significantly well in maintaining higher sorghum grain yield (1592.7 kg ha^{-1}) which was 14% higher compared to the minimum tillage practice (1397.2 kg ha^{-1}). Among the nutrient management treatments, when averaged over years as well as tillage, it was observed that, application of 2 t Gliricidia loppings + 20 kg N through urea to sorghum crop recorded significantly highest sorghum grain yield of 1706.3 kg ha^{-1} followed by both application of 4 t compost + 20 kg N through urea (1664.9 kg ha^{-1}) as well as 40 kg N through urea (1648.5 kg ha^{-1}) and were at par with each other. Apart form the control, the lowest grain yields were observed under application of sole organic sources of nutrients i.e. 4 t compost + 2 t gliricidia loppings (1597.0 kg ha^{-1}). When compared to control, the percent increase in sorghum grain yields under all the nutrient management treatments were: T4 =2 t Gliricidia loppings + 20 kg N through urea (98.8%) > T3 = 4 t compost + 20 kg N through urea (94.0%) = T2 = 40 kg N through urea (92.1%) > T5 = 4 t compost + 2 t gliricidia loppings (86.1%).

Table 151: Long-term effects of tillage and integrated nutrient management treatments on sorghum grain yields

Tillage	INM Treatments equal to 40 kg N ha^{-1}	Sorghum grain yields (kg ha^{-1})										Pooled Analysis	SYI	Agron. Eff.
		1998	1999	2000	2001	2002	2004	2005	2006	2007	2008			
Conventional tillage	T1 = Control	1067	1035	1114	900	923	795	816	827	869	708	905	0.33	-
	T2 = 40 kg N through urea	1675	1624	1760	1680	2344	2006	1596	1845	1613	1466	1761	0.63	21.4
	T3 = 4 t compost + 20 kg N through urea	1665	1458	1923	1617	2383	2027	1470	1849	1774	1556	1772	0.62	21.7
	T4 =2 t Gliricidia loppings + 20 kg N through urea	1645	1871	2002	1950	2367	2003	1427	1827	1890	1578	1856	0.67	23.8
	T5 = 4 t compost + 2 t gliricidia loppings	1675	1721	1733	1700	1931	1796	1310	1711	1734	1385	1670	0.62	19.1
Minimum tillage	T1 = Control	1171	888	867	750	893	704	586	731	917	604	811	0.27	-
	T2 = 40 kg N through urea	1652	1448	1305	1434	2130	1843	1107	1455	1701	1287	1536	0.52	18.1
	T3 = 4 t compost + 20 kg N through urea	1913	1086	1313	1458	2264	1938	1091	1440	1737	1336	1558	0.49	18.7
	T4 =2 t Gliricidia loppings + 20 kg N through urea	1540	1235	1451	1542	2132	1931	1120	1434	1789	1393	1557	0.52	18.6
	T5 = 4 t compost + 2 t gliricidia loppings	1663	1568	1285	1550	1918	1777	1135	1352	1673	1321	1524	0.54	17.8
LSD (0.05)	Between tillage means	187	118	206	13	270	280	132	57.59	291.1	36.0	23.6	-	-
	Between treatment means	121	114	279	197	192	517	71	102.3	124.6	136.4	37.2	-	-
	Between two treatment means at same tillage	172	162	395	279	272	99	101	144.7	176.2	NS	-	-	-
	Between two treatment means at same or different treatments	179	156	368	249	277	91	111	132.5	213.1	NS	-	-	-
	Years	-	-	-	-	-	-	-				52.7	-	-
	Years x Tillage	-	-	-	-	-	-	-				74.5	-	-
	Years x Treatments	-	-	-	-	-	-	-				117.8	-	-
	Tillage x Treatments	-	-	-	-	-	-	-				52.7	-	-
	Years x Tillage x Treatments	-	-	-	-	-	-	-				NS	-	-

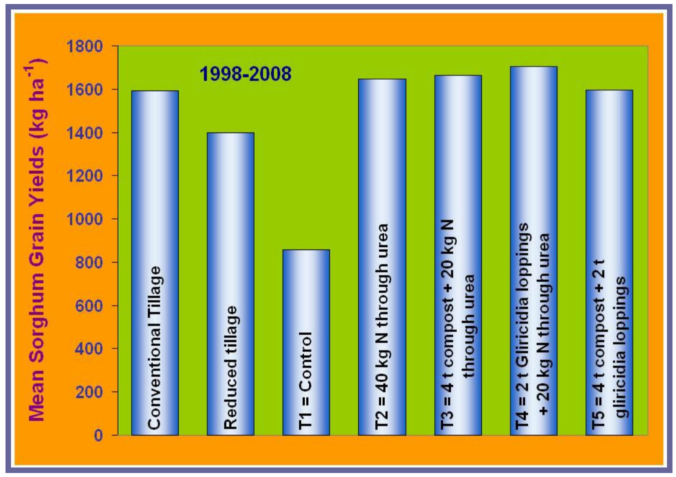

Fig 126: Sorghum average grain yields over a period of ten years (1998-2008) as influenced by tillage and nutrient management treatments under sorghum-mungbean strip cropping system in Alfisols of Hyderabad

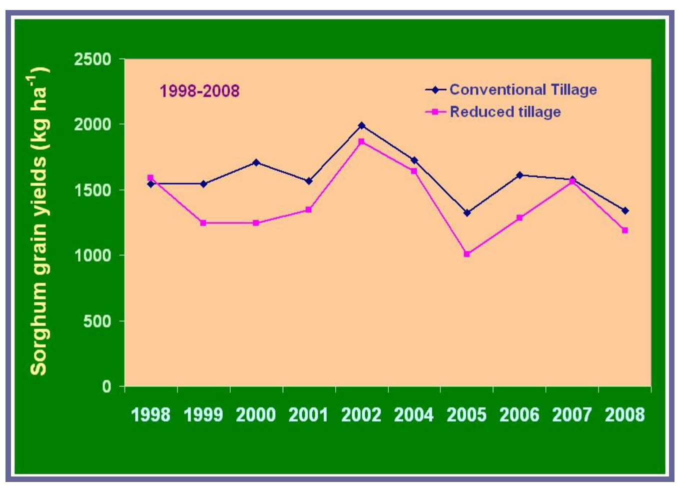

Fig 127: Sorghum grain yields during 1998-2008 as influenced by tillage practices under sorghum-mungbean strip cropping system in Alfisols of Hyderabad

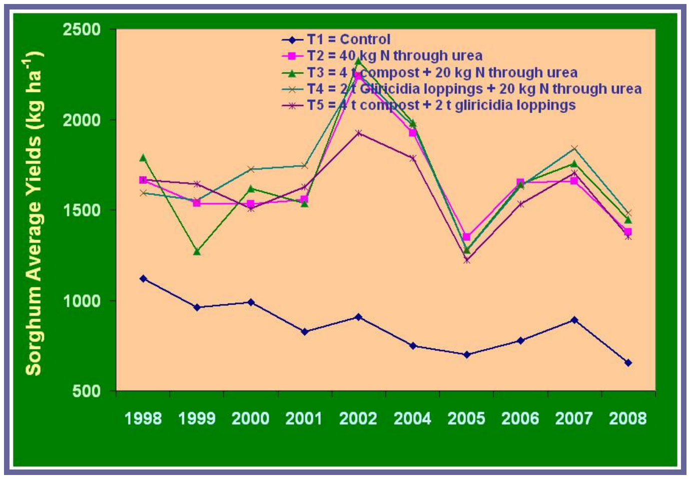

Fig 128: Sorghum grain yields during 1998-2008 as influenced by nutrient management treatments under sorghum-mungbean strip cropping system in Alfisols of Hyderabad

4.2.35.3. Mungbean grain yields as influenced by INM and tillage practices under sorghum- green gram strip cropping

As in case of sorghum, pooled analysis of grain yield data of mungbean as influenced by tillage and INM treatments was also done for a period of ten years and the data is presented in Table 152 & Fig 129 to 131. It is observed that, over a period of ten years, tillage as well as the nutrient management treatments played a significant influence on mungbean grain yields. Out of the ten years of experimentation, mung bean grain yields were highest (1204 kg ha^{-1}) during the year 2004 followed by the yields during the year 2007 (1030 kg ha^{-1}) while the lowest grain yields were recorded during the year 2000 (459.4 kg ha^{-1}). Of the two tillage methods, when averaged over the nutrient management treatments for a period of ten years, conventional tillage showed significantly higher mung bean grain yields (876.5 kg ha^{-1}) compared to minimum tillage ((814 kg ha^{-1}). The percent increase in mungbean grain yields under conventional tillage was to the extent of 8% over minimum tillage. Among the nutrient management treatments, when averaged over the tillage, application of 2 t compost + 10 kg N through urea recorded significantly highest mung bean grain yields (937.2 kg ha^{-1}) and was at par with other two treatments, viz., 2 t compost + 1 t gliricidia loppings (934 kg ha^{-1}) and 1 t Gliricidia loppings + 10 kg N through urea (926 kg ha^{-1}). When compared to control, the percent increase in mungbean grain yields under all the nutrient management treatments were: T3 = 2 t compost + 10 kg N through urea (61.9%) = T5 = 2 t compost + 1 t gliricidia loppings (61.3%) = T4 =1 t Gliricidia loppings + 10 kg N through urea (60.0%) > T2 = 20 kg N through urea (46.9%). The long-term yield trends of mung bean as influenced by tillage and INM treatments revealed that after tenth year of the study, the performance of reduced tillage on an average, was almost near to that of conventional tillage. This trend indicated that in case of legume like mung bean, the probability of success of reduced tillage is quite higher in rainfed Alfisol soil which is susceptible to hard setting and compaction. Hence, this finding raises the hope of success of reduced tillage practices in rainfed semi-arid tropical soils.

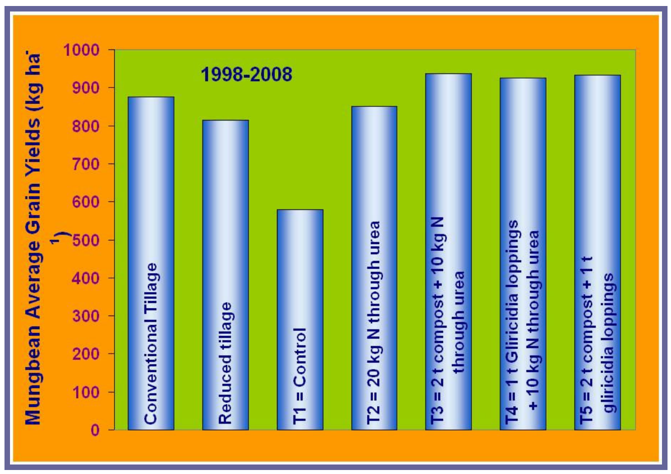

Fig 129: Mungbean average grain yields over a period of ten years (1998-2008) as influenced by tillage and nutrient management treatments under sorghum-mungbean strip cropping system in Alfisols of Hyderabad

Table 152: Long-term effects of tillage and integrated nutrient management treatments on mungbean grain yields

Tillage	INM Treatments equal to 20 kg N ha^{-1}	Mungbean grain yields (kg ha^{-1})										Pooled Analysis	SYI	Agron Eff.
		1998	1999	2000	2001	2002	2004	2005	2006	2007	2008			
Conventional tillage	T1 = Control	447	847	485	517	537	711	521	565	763	624	602	0.33	-
	T2 = 20 kg N through urea	653	1056	614	830	900	1129	962	889	877	948	886	0.51	14.2
	T3 = 2 t compost + 10 kg N through urea	827	1141	599	870	900	1438	938	1067	1110	992	988	0.53	19.3
	T4 =1 t Gliricidia loppings + 10 kg N through urea	684	1059	592	710	993	1402	901	910	1069	1089	941	0.49	17.0
	T5 = 2 t compost + 1 t gliricidia loppings	780	1137	702	830	721	1386	886	959	1180	1074	966	0.52	18.2
Minimum tillage	T1 = Control	628	633	224	490	520	700	408	604	867	481	556	0.26	-
	T2 = 20 kg N through urea	656	887	284	770	765	1288	692	929	1039	839	815	0.38	13.0
	T3 = 2 t compost + 10 kg N through urea	998	792	310	760	843	1392	747	955	1093	971	886	0.42	16.5
	T4 =1 t Gliricidia loppings + 10 kg N through urea	1021	761	418	700	743	1372	754	1042	1213	1082	911	0.44	17.8
	T5 = 2 t compost + 1 t gliricidia loppings	1046	912	366	880	706	1217	724	1013	1087	1070	902	0.45	17.3
LSD (0.05)	Between tillage means	73	93	18	67	210	35	171	NS	254.3	NS	16.5	-	
	Between treatment means	56	81	44	48	83	96	38	61.1	143.4	118.7	26.1	-	
	Between two treatment means at same tillage	79	115	62	69	117	188	54	86.3	202.8	NS	-	-	
	Between two treatment means at same or different treatments	79	112	56	70	148	71	97	81.5	220.4	NS	-	-	
	Years	-	-	-	-	-	-	-	-	-	-	36.9	-	
	Years x Tillage	-	-	-	-	-	-	-	-	-	-	52.2	-	
	Years x Treatments	-	-	-	-	-	-	-	-	-	-	82.5	-	
	Tillage x Treatments	-	-	-	-	-	-	-	-	-	-	NS	-	
	Years x Tillage x Treatments	-	-	-	-	-	-	-	-	-	-	116.7	-	

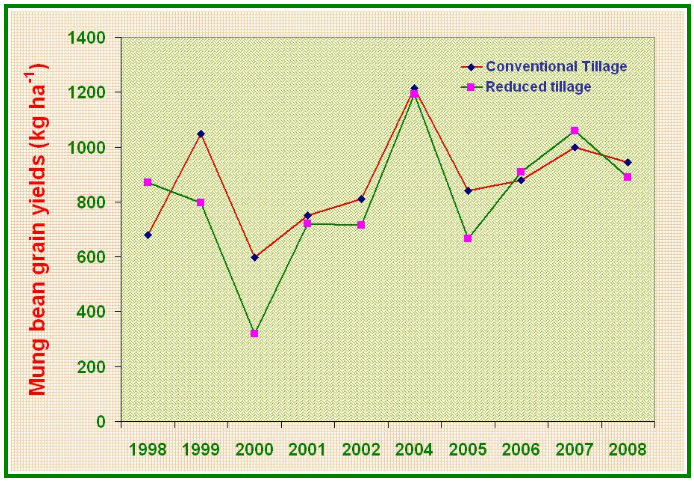

Fig 130: Influence of conventional and reduced tillage irrespective of INM treatments on mung bean grain yields over years (1998-2008) in sorghum-mung bean strip cropping system in rainfed Alfisol

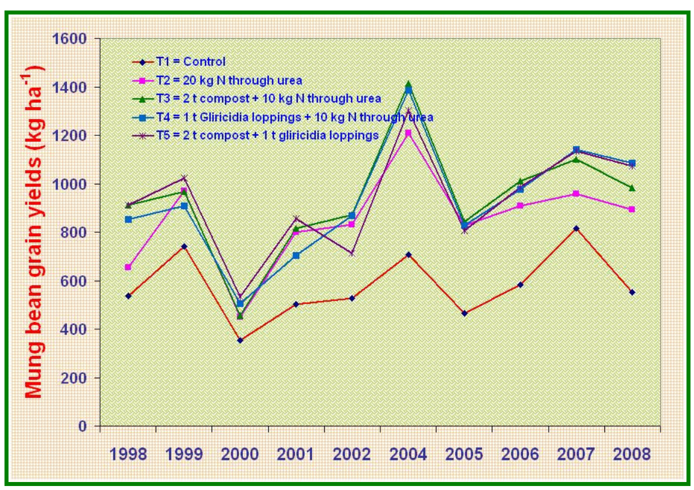

Fig 131: Influence of integrated nutrient management treatments irrespective of tillage on mung bean grain yields in sorghum-mung bean strip cropping system over years (1998-2008) in rainfed Alfisol

4.2.35.4. Sustainability Yield Indices (SYI) and Agronomic Efficiency (AE) as influenced by INM and tillage practices on under sorghum- green gram strip cropping

The Sustainability Yield Index (SYI) of the management treatments were also computed using the following relationship:

$$\textbf{SYI} = \frac{\overline{Y} - \sigma}{Y_{max}}$$

Where $\overline{Y}$ was average yield of a treatment, σ was treatment standard deviation and Y_{max} was maximum yield in the experiment over years.

For sorghum crop, the sustainability yield indices varied from 0.27 to 0.67 while the agronomic efficiency ranged from 18.1 to 23.8 kg grain kg^{-1} N across the management treatments under both conventional and reduced tillages (Fig 132 & 133). When averaged over the treatments, conventional tillage maintained the highest SYI (0.57) as well as agronomic efficiency (17.2 kg grain kg^{-1} N) compared to minimum tillage with an average SYI of 0.47 and agronomic efficiency of 14.7 kg grain kg^{-1} N. When averaged over the tillage effects, application of 2 t Gliricidia loppings + 20 kg N through urea maintained the highest SYI (0.60) as well as agronomic efficiency (21.2 kg grain kg^{-1} N) followed by other treatments. Among all the treatments, practice of conventional tillage + application of 2 t Gliricidia loppings + 20 kg N through urea in case of sorghum crop recorded significantly highest SYI (0.67) as well as AE (23.8 kg grain kg^{-1} N).

For mungbean crop, the sustainability yield indices varied from 0.26 to 0.52 while the agronomic efficiency varied from 13.0 to 19.3 kg grain kg^{-1} N across the management treatments under both conventional and minimum tillage plots. Similarly, in case of mung bean also, when averaged over the treatments, conventional tillage maintained higher SYI (0.47) as well as agronomic efficiency (13.7 kg grain kg^{-1} N) as compared to minimum tillage which maintained SYI of 0.39 and AE of 12.9 kg grain kg^{-1} N.

When averaged over the tillage effects, both application of 2 t compost + 1 t gliricidia loppings as well as 2 t compost + 10 kg N through urea more or less maintained similar level of SYI and AE compared to other treatments. Among all the treatments, practice of conventional tillage + 2 t compost + 1 t gliricidia loppings maintained higher SYI (0.52) while practice of conventional tillage +2 t compost + 10 kg N through urea maintained higher agronomic efficiency (19.2 kg grain kg^{-1} N) under mung bean crop.

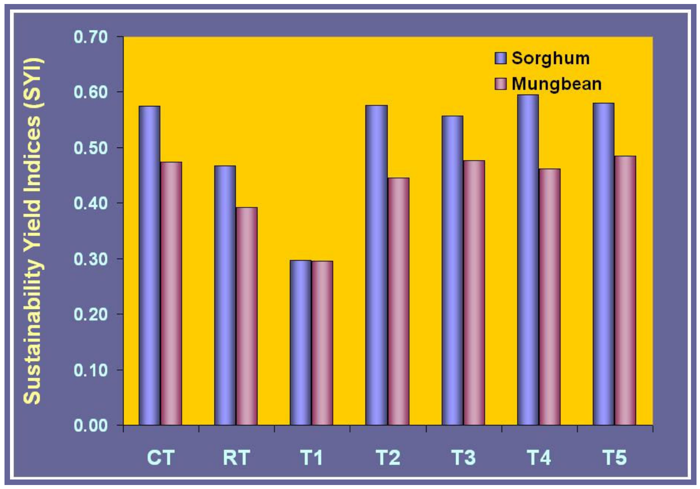

Fig 132: Average sustainability yield indices of sorghum and mungbean as influenced by tillage and INM practices over a period of 10 years in Alfisols of Hyderabad

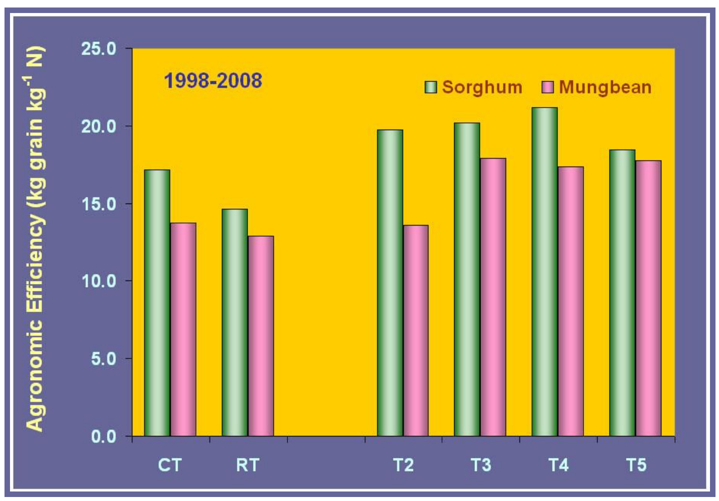

Fig 133: Agronomic efficiency of sorghum and mungbean as influenced by tillage and INM practices over a period of 10 years in Alfisols of Hyderabad

4.2.35.5. Assessment of soil quality as influenced by INM and tillage practices under sorghum- green gram strip cropping

Soil samples from 0-20 cm depth were collected from the experimental site after seventh year (during 2005) of the study and were partitioned and passed through 8 mm, 4.75 mm, 2 mm, differently and saved for further different kind of analysis. Soil samples passed through 8 mm sieve and retained on the 4.75 mm sieve were used for aggregate analysis using Yoder's apparatus. Soil samples passed through 2 mm sieve were used for chemical analysis for pH, EC, N, P, K, Ca, Mg, S, and micronutrients such as Zn, Fe, Cu, Mn and B. A portion of 2 mm sieved sample was further grinded and passed through 0.2 mm sieve for organic carbon estimation. For biological properties like microbial biomass carbon, 2mm sieved soil samples were stored in at a low temperature, similarly, for dehydrogenase assay, the 2mm sieve processed samples were stored separately in a refrigerator for further analysis. Bulk density was measured in the field by core method. The methods adopted for the estimation of various parameters have already given in earlier section.

Soil reaction under both the conventional and low tillage plots varied from 6.27 to 6.85 and was not significantly affected by integrated nutrient management treatments. Electrical conductivity in the soils varied form 0.05 to 0.13 dS m^{-1}. Almost all the treatments under both conventional and minimum tillage plots recorded EC ranging from 0.05 to 0.09 dS m^{-1} except under 4 t compost + 20 kg N through urea under conventional tillage, which recorded an EC of 0.13 dS m^{-1}. Organic carbon in the soil ranged from 6.0 to 7.2 g kg^{-1} under both the tillage conditions. Tillage did not show much effect on organic carbon content in the soils. But the integrated nutrient management treatments had a significant effect on organic carbon content. Highest amount of organic carbon under conventional tillage plots was observed in 4 t compost + 2 t gliricidia loppings (6.5 g kg^{-1}), a purely organic treatment followed by 2 t Gliricidia loppings + 20 kg N through urea (6.3 g kg^{-1}). In case of low tillage, 4 t compost + 2 t gliricidia loppings recorded the highest amount of organic carbon (7.2 g kg^{-1}) followed by 4 t compost + 20 kg N through urea (7.0 g kg^{-1}) (Table 153, Fig 134).

Available nitrogen in the soils had the same trend as it was recorded in organic carbon. Application of 4 t compost + 2 t gliricidia loppings recorded the highest amount of available nitrogen under both conventional (170 kg ha^{-1}) and reduced tillage (191 kg ha^{-1}). Available phosphorus in the soils ranged from 23.19 to 36.78 kg ha^{-1}. Under conventional tillage, the application of 4 t compost + 2 t gliricidia loppings recorded the highest amount of available phosphorus (36.78 kg ha^{-1}) followed by application of 2 t gliricidia loppings + 20 kg N through urea (36.62 kg ha^{-1}). While under reduced tillage, application of 4 t compost + 20 kg N through urea recorded the highest available phosphorus (33.57 kg ha^{-1}) followed by 4 t compost + 2t gliricidia loppings (31.54 kg ha^{-1}). Available potassium in the soils ranged from 134.58 to 164.76 kg ha^{-1} across both the tillage systems under conjunctive nutrient use treatments. While tillage had no significant effect on the available potassium in the soils, the integrated nutrient management treatments had significant effect on available potassium. Under conventional tillage, highest amount of available potassium was recorded under application of 4t compost + 20 kg N through urea (164.05 kg ha^{-1}) while under reduced tillage, 4t compost + 2t gliricidia loppings recorded the highest available potassium of 164.76 kg ha^{-1} (Table 153, Fig 135).

Exchangeable calcium content in the soils was neither affected by tillage nor INM treatments whereas, the INM treatments had significant influence on the exchangeable magnesium content. Both the exchangeable calcium and magnesium in the soils ranged from 2.97 to 4.69 cmol kg^{-1} and 0.80 to 1.73 cmol kg^{-1} respectively. Under conventional tillage, exchangeable magnesium was highest under the treatments receiving 40 kg N through urea (1.54 cmol kg^{-1}) while under reduced tillage, application of 4t compost + 2t gliricidia loppings recorded the highest exchangeable magnesium of 1.73 cmol kg^{-1}. Tillage and application of INM treatments had significant influence on available sulphur in soils. On an average over INM treatments, conventional tillage plots recorded 10.20 μg g^{-1} of available sulphur, while reduced tillage plots recorded 11.60 μg g^{-1} of available sulphur. Among the INM treatments under both conventional tillage and reduced tillage, application of 40 kg N through urea recorded highest available sulphur of 13.13 μg g^{-1} and 13.06 μg g^{-1} respectively, followed by 2t gliricidia loppings + 20 kg N through urea (10.93 μg g^{-1} and 12.83 μg g^{-1} respectively) (Table 153, Fig 136).

Available zinc in the soils varied form 0.85 to 1.42 μg g^{-1} across the treatments under both conventional and minimum tillage. Under conventional tillage, highest amount of zinc in the soil was recorded under 4t compost + 2t gliricidia loppings (1.28 μg g^{-1}). Under reduced tillage, 2 t gliricidia loppings + 20 kg N through urea recorded the highest amount of zinc content in the soils. Available iron status in the soil was highest under application of 40 kg N through urea (10.68 μg g^{-1}) followed by 4t compost + 20 kg N through urea (10.63 μg g^{-1}) in conventional tillage. While under reduced tillage, application of 2 t gliricidia loppings +20 kg N through urea recorded the highest amount of zinc in the soils (12.13 μg g^{-1}) followed by 40 kg N through urea (11.39 μg g^{-1}). Available manganese in the soils ranged from 10.99 to 16.46 μg g^{-1}. Application of 40 kg N through urea under both conventional tillage and reduced tillage recorded an available manganese status of 16.46 μg g^{-1} and 14.49 μg g^{-1} respectively. Boron in the soils varied from 0.35 to 0.98 μg g^{-1} across both the tillage as well as the INM treatments. Application of 2 t gliricidia loppings + 20 kg N through urea recorded the highest amount of boron of 0.95 and 0.98 μg g^{-1} under both conventional tillage and reduced tillage respectively (Table 154, Fig 137).

The conjunctive use of organic and inorganic sources of nutrients had significant influence on some of the biological attributes of soil such as the dehydrogenase assay, microbial biomass carbon, labile carbon, microbial biomass nitrogen, bulk density and mean weight diameter of the soils aggregates, while tillage alone did not show much influence on these properties. On the other hand, tillage in combination with the INM treatments had significant influence on dehydrogenase assay and labile carbon content of the soils. Dehydrogenase assay in the soil varied form 1.29 to 2.60 μg TPF $hr^{-1}g^{-1}$ across the various treatments under both the tillage practices. Highest dehydrogenase activity was recorded under application of 40 kg N through urea (1.94 μg TPF $hr^{-1}g^{-1}$) under conventional tillage. While under reduced tillage, dehydrogenase activity was highest under application of 4 t compost + 2 t gliricidia loppings (2.60 μg TPF $hr^{-1}g^{-1}$) followed by 2t gliricidia loppings + 20 kg N through urea (2.20 μg TPF $hr^{-1}g^{-1}$). Microbial biomass carbon in the soils varied form 115.10 to 172.03 μg g^{-1} of soil. Application of 4 t compost + 2t gliricidia loppings recorded the highest microbial biomass carbon content of 162.40 and 172.03 μg g^{-1} of soil under both conventional and reduced tillage respectively which was followed by 2t gliricidia loppings + 20 kg N through urea under conventional tillage (152.68 μg g^{-1} of soil) and reduced tillage (163.59 μg g^{-1} of soil). Labile carbon in the soils ranged from 203.11 to 264.98 mg kg^{-1}. Application of 4t compost + 2t gliricidia loppings recorded the highest labile carbon content of 257.03 and 264.98 mg kg^{-1} under both conventional and reduced tillage respectively followed by application of 40 kg N through urea (245.85 and 246.52 mg kg^{-1} respectively). Microbial biomass nitrogen in the soil varied from 42.35 to 62.93 kg ha^{-1}. Application of 4 t compost + 2t gliricidia loppings recorded the highest microbial biomass nitrogen of 59.81 and 62.93 kg ha^{-1} under conventional and reduced tillage respectively. Bulk density and mean weight diameter of the soils varied form 1.72 to 1.80 Mg m^{-3} and 0.11 to 0.18 mm respectively across the treatments under both the tillage practices. Hydraulic conductivity of the soils varied from 2.28 to 4.08 cm hr^{-1} (Table 155, Fig 138)

Table 153: Long-term effects of tillage and integrated nutrient management treatments on soil properties under sorghum greengram strip cropping in Alfisols of Hyderabad

Tillage	INM Treatments equal to 40 kg N ha^{-1}	pH	EC	OC ($g\ kg^{-1}$)	N	P	K	Ca	Mg	S
					($kg\ ha^{-1}$)			$cmol\ kg^{-1}$		$\mu g\ g^{-1}$
Conventional tillage	T1 = Control	6.31	0.06	5.6	144.32	31.75	134.58	2.97	1.17	8.38
	T2 = 40 kg N through urea	6.27	0.05	6.0	156.43	30.18	140.92	3.48	1.54	13.13
	T3 = 4 t compost + 20 kg N through urea	6.85	0.13	6.2	168.40	31.21	164.05	4.69	1.48	8.67
	T4 = 2t Gliricidia loppings + 20 kg N thru urea	6.54	0.06	6.3	162.82	36.62	140.58	3.35	1.51	10.93
	T5 = 4 t compost + 2 t gliricidia loppings	6.59	0.09	6.5	170.45	36.78	147.00	3.72	1.39	9.86
Minimum tillage	T1 = Control	6.82	0.06	5.7	146.34	23.19	136.39	3.67	0.80	8.04
	T2 = 40 kg N through urea	6.62	0.07	6.1	160.46	27.54	144.39	3.72	1.11	13.06
	T3 = 4 t compost + 20 kg N through urea	6.64	0.08	7.0	174.37	33.57	145.64	3.56	1.32	11.47
	T4 = 2t Gliricidia loppings + 20 kg N thru urea	6.64	0.07	6.6	170.22	29.37	140.13	3.57	1.20	12.83
	T5 = 4 t compost + 2 t gliricidia loppings	6.75	0.08	7.2	191.37	31.54	164.76	3.74	1.73	12.60
LSD (0.05)	Between tillage means	*0.14*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*1.09*
	Between treatment means	*NS*	*.027*	*0.37*	*8.22*	*3.08*	*9.38*	*NS*	*0.13*	*1.44*
	Between two treatment means at same tillage	*NS*	*NS*	*NS*	*NS*	*4.36*	*13.26*	*NS*	*NS*	*NS*
	Between two treatment means at same or different treatments	*NS*	*NS*	*NS*	*NS*	*5.48*	*20.45*	*NS*	*NS*	*NS*

Table 154: Long-term effects of tillage and integrated nutrient management treatments on soil micronutrients under sorghum greengram strip cropping in Alfisols of Hyderabad

Tillage	INM Treatments equal to 40 kg N ha^{-1}	Zn	Fe	Cu	Mn	B
				μg g^{-1}		
Conventional tillage	T1 = Control	0.88	8.43	0.82	11.79	0.41
	T2 = 40 kg N through urea	1.10	10.68	1.08	16.46	0.66
	T3 = 4 t compost + 20 kg N through urea	1.15	10.63	1.07	15.30	0.82
	T4 = 2t Gliricidia loppings + 20 kg N thru urea	1.17	9.57	0.89	12.97	0.95
	T5 = 4 t compost + 2 t gliricidia loppings	1.28	7.56	0.91	11.96	0.75
Minimum tillage	T1 = Control	0.85	6.60	0.81	10.99	0.35
	T2 = 40 kg N through urea	1.05	11.39	1.02	14.49	0.70
	T3 = 4 t compost + 20 kg N through urea	1.18	8.68	0.93	13.06	0.84
	T4 = 2t Gliricidia loppings + 20 kg N thru urea	1.42	12.13	0.98	10.93	0.98
	T5 = 4 t compost + 2 t gliricidia loppings	1.29	7.15	0.83	11.21	0.76
LSD (0.05)	Between tillage means	*NS*	*NS*	*NS*	*1.42*	*NS*
	Between treatment means	*0.065*	*1.27*	*0.087*	*1.30*	*0.036*
	Between two treatment means at same tillage	*0.092*	*1.80*	*NS*	*NS*	*NS*
	Between two treatment means at same or different treatments	*0.088*	*1.64*	*NS*	*NS*	*NS*

Table 155: Long-term effects of tillage and integrated nutrient management treatments on soil biological and physical properties under sorghum greengram strip cropping in Alfisols of Hyderabad

Tillage	INM Treatments equal to 40 kg N ha^{-1}	Dehydrogenase assay (µg TPF $hr^{-1}g^{-1}$)	Microbial biomass carbon (µg g^{-1} of soil)	Labile carbon (mg kg^{-1})	Microbial biomass nitrogen (kg ha^{-1})	Bulk density (Mg m^{-3})	MWD (mm)	HC (cm hr^{-1})
Conventional tillage	T1 = Control	1.51	115.10	203.11	42.35	1.80	0.11	3.27
	T2 = 40 kg N through urea	1.94	142.86	245.85	52.58	1.74	0.12	3.78
	T3 = 4 t compost + 20 kg N through urea	1.83	152.66	231.76	56.21	1.74	0.14	3.87
	T4 = 2t Gliricidia loppings + 20 kg N thru urea	1.84	152.68	244.51	56.19	1.74	0.12	3.83
	T5 = 4 t compost + 2 t gliricidia loppings	1.77	162.40	257.03	59.81	1.73	0.13	4.08
Minimum tillage	T1 = Control	1.29	125.87	230.90	46.05	1.78	0.12	2.28
	T2 = 40 kg N through urea	1.57	151.25	246.52	55.33	1.74	0.13	2.61
	T3 = 4 t compost + 20 kg N through urea	1.53	155.83	232.74	57.02	1.74	0.16	2.90
	T4 = 2t Gliricidia loppings + 20 kg N thru urea	2.20	163.59	244.93	59.85	1.72	0.13	2.82
	T5 = 4 t compost + 2 t gliricidia loppings	2.60	172.03	264.98	62.93	1.72	0.18	3.32
LSD (0.05)	Between tillage means	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*0.16*
	Between treatment means	*0.16*	*7.72*	*9.42*	*2.85*	*0.03*	*0.017*	*0.17*
	Between two treatment means at same tillage	*0.23*	*NS*	*13.33*	*NS*	*NS*	*NS*	*NS*
	Between two treatment means at same or different treatments	*0.23*	*NS*	*12.85*	*NS*	*NS*	*NS*	*NS*

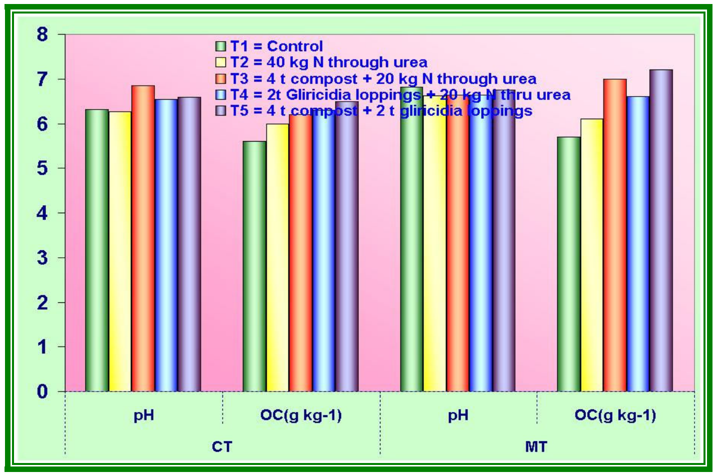

Fig 134: Long-term effect of tillage and INM treatments on soil reaction and organic carbon under sorghum-greengram strip cropping in Alfisols of Hyderabad

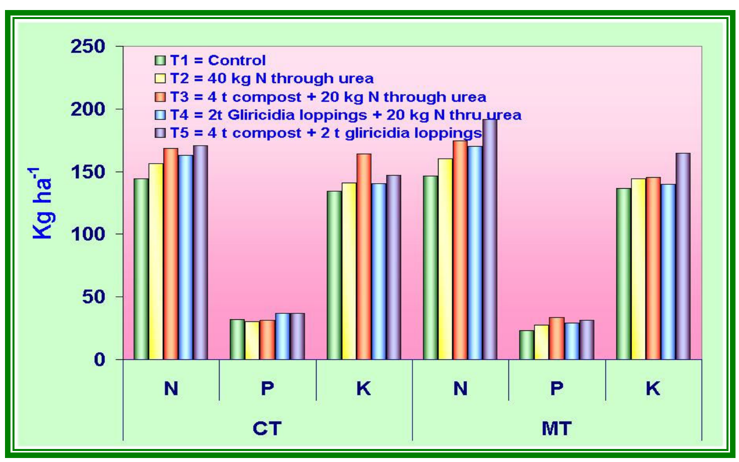

Fig 135: Long-term effect of tillage and INM treatments on major nutrients under sorghum-greengram strip cropping in Alfisols of Hyderabad

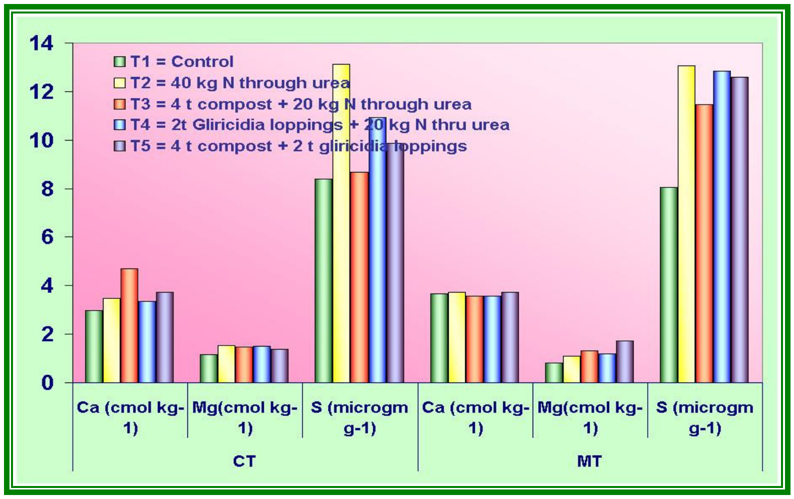

Fig 136: Long-term effect of tillage and INM treatments on secondary nutrients under sorghum-greengram strip cropping in Alfisols of Hyderabad

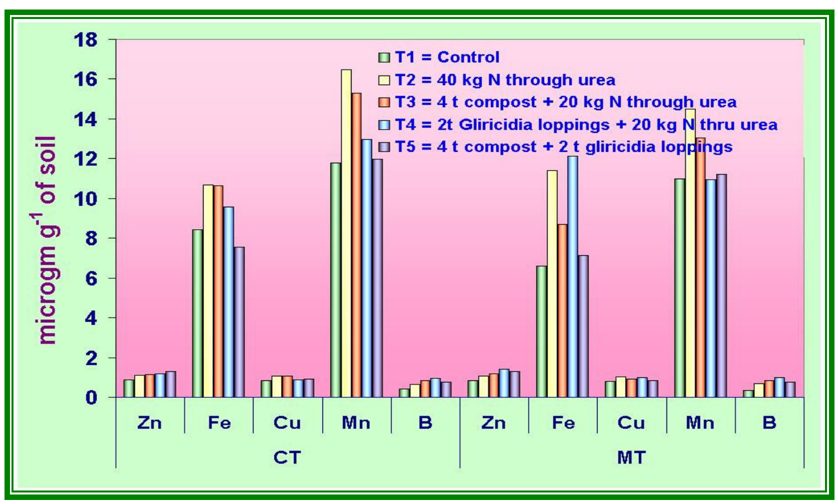

Fig 137: Long-term effect of tillage and INM treatments on micronutrients under sorghum-greengram strip cropping in Alfisols of Hyderabad

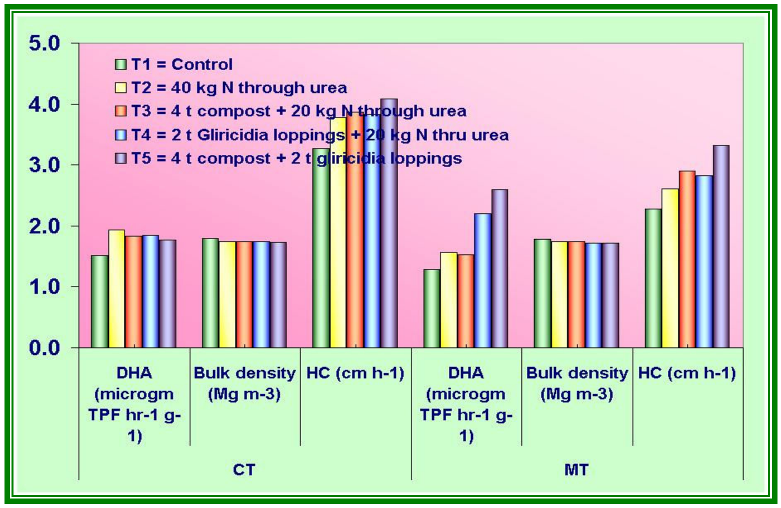

Fig 138: Long-term effect of tillage and INM treatments on soil biological and physical nutrients under sorghum–greengram strip cropping in Alfisols of Hyderabad

4.2.35.6. Computation of soil quality index

In order to identify the best treatments from the view point of soil quality improvement and sustainability, key indicators were identified using a huge data set generated through laboratory analysis. Soil quality indices (SQI) were also computed by using the latest methodology. The various steps of the methodology were given in earlier section.

To select a representative minimum data set (MDS), the method suggested by Doran and Parkin, 1994 and Andrews et al., 2002a was used. According to this procedure, preferably those soil properties which get significantly influenced by the management treatment should be considered. In the present set of data, only exchangeable calcium showed non- significant effect. So all the variables were considered for Principle Component Analysis (PCA). Principal components (PC) for a data set are defined as linear combinations of variables that account for maximum variance within the set by describing vectors of closet fit to the n observation in p-dimensional space, subject to being orthogonal to one another. The principal components receiving high eigen values and variables with high factor loading were assumed to be variables that best represented system attributes. Therefore, only the PCs with eigen values ≥ 1 (Brejda et al., 2000) and those that explained at least 5% of the variation in the data (Wander and Bollero, 1999) were examined. Within each PC, only highly weighted factors were retained for MDS. Highly weighted factor loadings were defined as having absolute values within 10% of the highest factor loading (Table 156). When more than one factor was retained under a single PC, multivariate correlation coefficients were employed to determine if the variables could be considered redundant and therefore eliminated from the MDS (Andrews et al., 2002a). Well-correlated variables were considered redundant and only one was considered for the MDS. The rest were eliminated from the data set. However, flexibility criteria were also followed depending upon the importance of the variable. If the highly weighted variables were not correlated, each was considered important and was retained in the MDS.

In PC1, the four variables qualified for the next step were: available N, DTPA-Zn, microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN). However, all these variables were found well correlated ($r > 0.70$) in the inter-correlation study as per the criteria suggested by Andrews *et al*. (2002a) (Table 157). Since the semi-arid tropical soils suffer from poor fertility especially available N and Zn, they were considered important from the viewpoint of soil fertility and were retained. Further, based on well correlation criteria, MBC and MBN were considered as representative indicators of each other and only MBC was retained being an important biological soil quality indicator. Finally in PC1, available N, Zn and MBC were retained for the minimum data set (MDS).

In PC2, among the three variables viz., pH, EC and Ca which were found qualified, pH and Ca, though not well correlated ($r > 0.7$) were found to have significant correlation. As the soil reaction was slightly acidic to near neutral, pH was not found a major constraint and hence was dropped from the MDS. Considering the importance of Ca in plant nutrition in these soils, among this group of variables, only Ca was retained for the MDS and the rest of the variables were eliminated. Similar to PC2, in PC 3, Cu and Mn, though not well correlated (< 0.70), were significantly correlated with each other among which, only one variable was needed to be retained. As the Mn content in these Alfisol was much above the critical limit in soil set for plant availability (> 2.5 $\mu g\ g^{-1}$), it was considered redundant and Cu, which was ≤ 1 $\mu g\ g^{-1}$, was retained for the final MDS. In PC4, among the significantly correlated variables viz., available phosphorus (P) and hydraulic conductivity (HC), only HC was retained, as it is one of the representative variables of physical properties of Alfisol which suffer from crusting and hard setting tendencies and low water retention. As the available P content in soil was adequate (> 25 kg ha^{-1}), it was eliminated from the MDS. In PC 5, only one variable i.e. mean weight diameter (MWD) of the soil aggregates was found qualified which was retained for the MDS. As a whole, from PC 1 to PC 5, the variables qualified and retained for final MDS were: available N, DTPA- Zn and Cu, MBC, exchangeable Ca, HC and MWD.

As a check of how well the MDS represented the management system goals, and to identify the key indicators, multiple regressions were performed using the indicators retained in the MDS as independent variables and the end point measures like mean yields of sorghum and mung bean, SYI's of sorghum and mung bean and soil organic carbon as dependent variables (Table 158). When the MDS was regressed with these functional goals, coefficient of determination (R^2) varied from 0.72 to 0.93. The variables which were found significant at P = 0.000 to 0.083 were accepted for the final MDS. Hence, based on the series of analytical data screening steps, only available N, Zn, Cu, MBC, MWD and HC were found declared as the key indicators for Alfisol under sorghum - mung bean system under conventional and reduced tillage.

After identifying the MDS indicators, every observation of each MDS indicator was transformed using a linear scoring method as suggested by Andrews *et al*. (2002b). To assign the scores, indicators were arranged in order depending on whether a higher value was considered "good" or "bad" in terms of soil function. In case of 'more is better' indicator, each observation was divided by the highest observed value such that the highest observed value received a score of 1. For 'less is better' indicator, the lowest observed value (in the numerator) was divided by each observation (in the denominator) such that the lowest observed value received a score of 1. In this study, all the indicators retained in the MDS were considered good from the view point of soil quality when they are in increasing order and hence "more is better" approach was followed. After transformation using linear scoring method, the MDS indicators scores thus obtained for each observation were multiplied with the weighted factor obtained from the PCA results Each PC explained a certain amount (%) of the variation in the total data set. This percentage when divided by the total percentage of variation explained by all the PCs with eigenvectors > 1, gave the weighted factors for indicators chosen under a given PC. The weighted factors (percent variation of each PC divided by the cumulative percent variation explained by all the PCs) for PC1, PC2, PC3, PC4 and PC5 were 0.50, 0.17, 0.16, 0.11 and 0.06 respectively.

After performing these steps, to obtain soil quality indices (SQI), the weighted MDS indicator scores for each observation were summed up using the following relationship:

$$SQI = \sum_{i=1}^{n} (Wi \times Si)$$

where Si is the score for the subscripted variable and Wi is the weighing factor obtained from the PCA. The soil quality indices thus obtained were normalized with respect to the maximum possible SQI i.e. summation of maximum PCA weighting factors of each key indicator and the data are presented in Table 159.

The results revealed that the SQI varied from 0.66 (control) to 0.86 (4 Mg compost + 20 kg N through urea) under conventional tillage, while under reduced tillage, it varied from 0.66 (control) to 0.89 (4 Mg compost + 2 Mg gliricidia loppings). Tillage alone did not show any significant effect on SQI, while the conjunctive nutrient use treatments significantly influenced the SQI in these SAT Alfisols. Among all the treatments, when averaged over tillage, application of 4 Mg compost + 2 Mg gliricidia loppings showed the highest SQI (0.87) followed by 2 Mg gliricidia loppings + 20 kg N through urea (0.84) which was at par with 4 Mg compost + 20 kg N through urea (0.82). The interaction effects of tillage and conjunctive nutrient use treatments were also found significant on SQI. On an average, under both CT and RT, the sole organic treatment out-performed in aggrading the soil quality to the extent of 31.8 % over control. The conjunctive nutrient use treatments aggraded the soil quality by 24.2 to 27.2 %, while the sole inorganic treatment could aggrade only to the extent of 18.2 % over the control. Interestingly, even the control which did not receive any N input in the form of treatment, except phosphorus, also maintained SQI of as high as 0.66. This may be attributed to the beneficial effect of legume crops grown in rotation with cereals, as various rotations, mainly cereal/legumes, combined with reduced tillage, could influence soil organic matter and associated aggregation and related hydraulic properties (Masri and Ryan 2006). In the present study, the overall order of superiority of the treatments from the viewpoint of soil quality indices was: T5>T4 = T3> T2>T1.

In order to know the contribution of each of the indicators towards soil quality, their average linear scores under each soil-nutrient management treatments were computed and have been depicted in Fig 139. Considering the average linear scores, the order of importance of the key indicators in influencing soil quality was MBC (0.41) = available N (0.41) > DTPA- Zn (0.37) > DTPA- Cu (0.12) > HC (0.09) > MWD (0.04) with a corresponding contribution of 28.5%, 28.6%, 25.3%, 8.6%, 6.1% and 2.9% respectively in these soils (140). This showed that these key indicators have considerable role to play in influencing various soil functions and in turn the functional goals.

In order to establish the quantitative relationship between SQI and functional goals, linear regressions were worked out between yields and SYI's of sorghum and mung bean as dependent variables (Y) and SQI as independent variable (x). The linear regression equations along with linear regression coefficient (R^2) are given in Table 160. The regression coefficients varied from a minimum of 0.39 with mung bean SYI and a maximum of 0.67 with mung bean yield and were found highly significant. These simple equations help in understanding the changes in functional goals with a given change in SQI.

Our study has clearly indicated that in semi arid tropical rainfed Alfisol, available N, DTPA – Zn & Cu, MBC, MWD and HC were the key indicators of 'soil quality'- which greatly influence the soil functions and overall soil quality and in-turn help in achieving the functional goals. Among these indicators, the available nitrogen contributing 28.5% towards soil quality in the present study is low in these soils. This happens because the major part of nitrogen in soil comes from soil organic matter (Smith and Elliott, 1990) which itself is very low because of SAT nature of the climate. Nitrogen plays an important role in soil and plant functions. It is a well-established fact that the vegetative growth of a plant is primarily governed by soil nitrogen. Adequate supply of nitrogen not only helps in improving the above ground biomass and grain yields, but also plays an important role in improving the below ground biomass by way of contributing more root biomass. This in turn, is very crucial for improving soil organic carbon and influencing the mineralization and immobilization processes and other rhizosphere activities, ultimately leading to improved functional capacity of soil. Further, among the chemical soil quality indicators, DTPA extractable Zn and Cu have also emerged as important key indicators contributing about 25.3% and 8.6% respectively towards relative soil quality indices. Since the soils in the present study were slightly acidic in reaction, these two elements play a crucial role in influencing the soil and plant functions. Among the biological soil quality indicators, microbial biomass carbon emerged as the key indicator contributing about 28.5 % towards soil quality indices. Soil microbial biomass is a labile source and sink of nutrients influencing predominant soil functions such as nutrient availability and their cycling and is a good indicator of potential microbial activity (Dalal and Mayer 1987; Myrold 1987). Therefore, any management practice that helps in improving MBC in soil would definitely contribute towards aggradation or improvement of soil quality. Among the set of physical soil quality indicators, MWD and HC qualified as the key indicators contributing about 2.9 % and 6.1% respectively towards soil quality indices. It is well established that MWD is an index presenting the structure of soil and the quality of organic inputs as well as the quantity (Tisdall and Oades 1982). However, MWD is mostly affected by quantity of organic matter, types of clays, wetting and drying, freezing and thawing, types and amounts of electrolytes, biological activity, cropping systems and tillage practices (Arshad *et al*. 1996). Further HC also has a great importance for these soils as it influences the predominant soil functions such as water infiltration rate, aeration, porosity, conductance and transmission of water, etc., and could be a good predictor of soil quality. Keeping in view the foregoing discussion, the set of key indicators qualified in the present study was considered as the most relevant to compute soil quality for these soils under sorghum – mung bean system.

Table 156: Results of principle component analysis (PCA) of soil quality indicators

PC's	PC 1	PC 2	PC 3	PC 4	PC 5
Eigen value	8.564	2.925	2.669	1.951	1.037
% of variance	40.782	13.930	12.712	9.290	4.939
Cumulative %	40.782	54.712	67.424	76.714	81.652
Factor loading/Eigen vector Variable					
pH	0.257	**0.790**	-0.064	-0.313	-0.159
EC	0.412	**0.780**	0.260	0.150	-0.086
Organic carbon	0.793	0.110	-0.340	-0.028	-0.009
Available N	**0.816**	-0.056	-0.276	-0.009	0.039
Available P	0.407	-0.303	-0.082	**0.721**	-0.223
Available K	0.589	0.602	0.095	0.183	0.219
Exchangeable Ca	0.360	**0.765**	0.375	-0.057	-0.051
Exchangeable Mg	0.722	-0.142	0.129	0.454	0.281
Available S	0.546	-0.531	0.045	-0.424	0.350
Zn	**0.863**	-0.201	-0.109	-0.057	-0.291
Fe	0.213	-0.357	0.697	-0.381	-0.119
Cu	0.328	-0.060	**0.821**	-0.188	-0.018
Mn	0.132	-0.057	**0.825**	0.096	0.361
B	0.810	-0.216	0.184	-0.043	-0.369
Dehydrogenase Assay (DHA)	0.774	-0.164	-0.151	0.031	0.244
Microbial biomass carbon (MBC)	**0.907**	-0.071	-0.113	-0.161	-0.177
Bulk density (BD)	-0.778	0.077	-0.084	0.203	-0.000
Mean weight diameter (MWD)	0.632	0.248	-0.398	-0.007	**0.453**
Hydraulic conductivity (HC)	0.410	-0.097	0.343	**0.762**	-0.079
Labile carbon (LC)	0.749	-0.042	-0.131	-0.160	0.062
Microbial biomass nitrogen (MBN)	**0.919**	-0.006	-0.098	-0.134	-0.170

Table 157: Correlation matrix for highly weighted variables under PC's with high factor loading

PC 1 Variables	**N**	**Zn**	**MBC**	**MBN**
Nitrogen	1	.689**	.774**	.774**
Zn	.689**	1	.846**	.854**
MBC	.774**	.846**	1	0.997**
MBN	.774**	.854**	0.997**	1
PC 2 Variables	**pH**	**EC**	**Ca**	
pH	1	0.632	0.606**	
EC	0.632**	1	0.809**	
Ca	0.606**	0.809**	1	
PC 3 variables	**Cu**	**Mn**		
Cu	1	0.668**		
Mn	0.668**	1		
PC 4 variables	**P**	**HC**		
P	1	0.644**		
HC	0.644**	1		

* and ** indicates significant difference at $P = 0.05$ and $P = 0.01$, respectively

Table 158: Verification of minimum data set (MDS) variables through multiple regressions using functional goals as dependent variables – Identification of key indicators

Functional goals	R^2	Most significant MDS variables	Probability levels (P)
Average sorghum yield	0.78	MBC, Cu, HC	>0.115; >0.013; >0.001
Sustainability Yield Index of sorghum	0.82	MBC, Cu, HC	>0.066; >0.036; >0.000
Average Mung bean yield	0.89	Zn; MBC, Cu, HC	>0.083; >0.163; >0.004; >0.000
Sustainability Yield Index of Mung bean	0.93	Zn; Cu, HC	>0.163; >0.000; >0.000
Organic carbon	0.72	Zn, N, MWD	>0.117; >0.092; >0.064

Table 159: Effect of soil-nutrient management treatments on overall soil quality indices

	Conjunctive nutrient use treatments equal to 40 kg N ha^{-1}	Conventional tillage	Reduced tillage
1	T1 = Control	0.66	0.66
2	T2 = 40 kg N through urea	0.78	0.77
3	T3 = 4 Mg compost + 20 kg N through urea	0.83	0.82
4	T4 = 2t Gliricidia loppings + 20 kg N thru urea	0.80	0.87
5	T5 = 4 Mg compost + 2 Mg gliricidia loppings	0.86	0.89
LSD (0.05)	Between tillage means	NS	
	Between treatment means	0.02	
	Between two treatment means at same tillage	0.03	
	Between two treatment means at same or different tillage	0.03	

Table 160: Prediction equations for functional goals using normalized soil quality indices (SQI)

Goal or function	R^2	*P*	Regression equations
Average sorghum yield (Y_S)	0.56	>0.000	Y_S = -1018.6 + 3204.5 x SQI
Sustainability Yield Index of sorghum (SYI_S)	0.47	>0.000	SYI_S = -0.302 + 0.9592 x SQI
Average Mung bean yield (Y_{MB})	0.67	>0.000	Y_{MB} = -348.2 + 1448.9 x SQI
Sustainability Yield Index of Mung bean (SYI_{MB})	0.39	>0.000	SYI_{MB} = -0.104 + 0.5906 x SQI

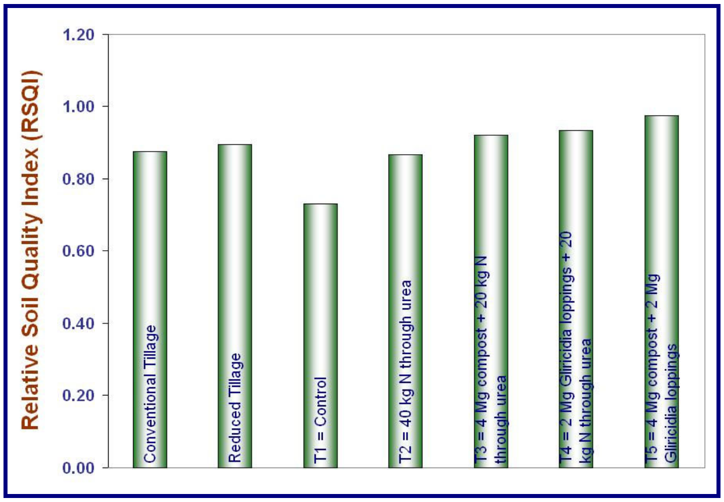

Fig 139: Relative soil quality index as influenced by tillage and conjunctive nutrients use treatments

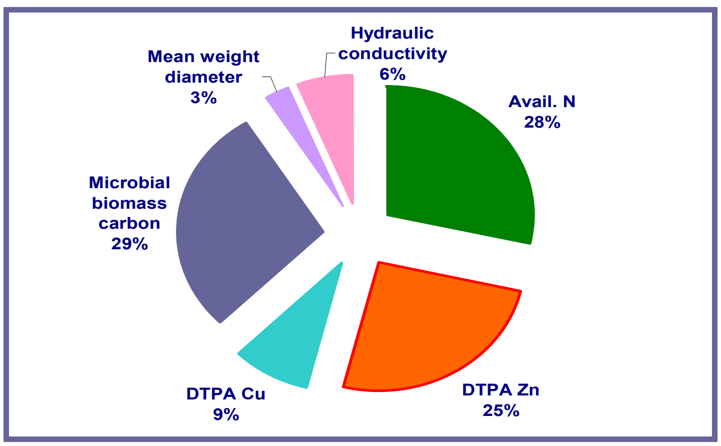

Fig 140: Percentage contribution of different soil quality parameters towards relative soil quality index in Alfisol

4.2.35.7. Carbon pools as influenced by INM and tillage practices under sorghum- green gram strip cropping after eight years of study (during 2006)

Soil organic matter is a key biological indicator of soil health. It is a direct outcome of the combined biological activity of plants, microorganisms and animals plus the myriad of biological factors. It has a great role to play in predominant soil functions such as aeration and soil fertility. Various researchers have divided SOM into pools of varying turnover times. After eight years of the study, various pools of carbon viz., organic carbon, inorganic carbon, microbial biomass carbon, oxidizable carbon, particulate organic carbon and total carbon as influenced by tillage and INM treatments were estimated using standard procedures (Table 161 & Fig 141 to 144).

Total organic carbon (TOC) in the soil ranged from 4.3 to 5.9 and 5.4 to 6.9 g kg^{-1} under conventional and minimum tillage plots respectively at 0-5 cm depth. At subsurface depth of 5-20 cm, the corresponding values varied between 4.3 to 5.7 and 5.4 to 6.7 g kg^{-1} respectively. Irrespective of the treatments, minimum tillage plots recorded significantly higher total organic carbon (TOC) of 6.1 and 6.0 g kg^{-1} at both surface and subsurface layers than the conventionally tilled plots. When averaged over tillage, sole organic treatment viz., 4 t compost + 2 t gliricidia loppings recorded the highest organic carbon content of 6.4 and 6.2 g kg^{-1} at surface and sub surface depths respectively. This was followed by the conjunctive organic and inorganic nutrient use treatments, while, sole inorganic treatment recorded significantly lower organic carbon content compared to conjunctive nutrient use treatments. The interactive effects of conventional tillage + 4 t compost + 2 t gliricidia loppings recorded significantly highest organic carbon content of 5.9 and 5.7 g kg^{-1} at surface and sub surface depths respectively while under minimum tillage also, the same treatment recorded significantly highest organic carbon content of 6.9 and 6.7 g kg^{-1} at surface and sub surface depths respectively.

Inorganic carbon in the soil ranged from 3.2 to 3.6 and 3.4 to 3.7 g kg^{-1} under conventional and minimum tillage plots respectively at surface depth of 0-5 cm. At the subsurface layer of 5-20 cm depth, the corresponding values ranged from 3.4 to 3.6 g kg^{-1} under both the tillage practices. Tillage had a significant influence on the inorganic carbon content of the soils only in the surface layer. When averaged over the treatments, minimum tillage recorded significantly higher inorganic carbon content of 3.6 g kg^{-1} compared to conventional tillage at surface layer.

Microbial biomass carbon being a measure of the living component of soil organic matter which excludes macro fauna and plant roots is considered as one of the important indicators of soil quality. In the present study, microbial biomass carbon in the soils ranged from 96.4 to 173.9 μg g^{-1} of soil and 97.6 to 174.8 μg g^{-1} of soil at surface depth of 0-5 cm under conventional and minimum tillages respectively. The corresponding values in the subsurface depth of 5-20 cm varied from 90.6 to 164.4 μg g-1 of soil and 96.2 to 153.4 μg g^{-1} of soil under conventional and minimum tillages respectively. Tillage did not show any significant influence on the microbial biomass carbon content at both surface and subsurface depths. Among the treatments, irrespective of the tillage, interestingly, 40 kg N through urea performed well and recorded relatively higher microbial biomass carbon of 174.36 μg g^{-1} of soil and 157.43 μg g^{-1} of soil at surface and subsurface depths respectively, followed by 4 t compost + 20 kg N through urea.

Dilute KMnO4 oxidizable carbon (labile carbon) in the soil as influenced by tillage and INM treatments, varied from 241.8 to 317.7 mg kg^{-1} and 257.7 to 307.3 mg kg^{-1} under conventional and minimum tillage respectively at surface depth of 0-5 cm. At the subsurface depth of 5-20 cm, the values ranged from 241.0 to 297.3 mg kg^{-1} and 251.2 to 297.0 mg kg^{-1} under conventional and minimum tillages respectively. The INM treatments had significant influence on oxidizable carbon at the surface depth only. Among all the treatments, 2 t gliricidia loppings + 20 kg N through urea recorded the highest oxidizable carbon of 310.3 mg kg^{-1} which was at par with 4 t compost + 2 t gliricidia loppings (299.7 mg kg^{-1}) at surface depth.

Particulate organic matter is a fraction of soil organic matter (SOM) that has the potential to serve as an indirect measure of soil health. This fraction plays an important role in soil aggregation either directly or indirectly by serving as a substrate for microbial activity. It is an important measure of soil health because its turn over time allows enough sensitivity to detect changes within a few years. As influenced by tillage and INM treatments, particulate organic carbon in the soil varied between 3.1 to 4.2 g kg^{-1} and 4.0 to 4.8 g kg^{-1} under conventional tillage and minimum tillage respectively under surface depth. At the subsurface depth of 5-20 cm, it ranged between 3.1 to 3.7 g kg^{-1} under conventional tillage and 3.1 to 4.5 g kg^{-1} under minimum tillage. Tillage had a significant influence on the particulate organic carbon at surface depth only but not at sub-surface depth. When averaged over the treatments, minimum tillage recorded significantly higher particulate organic carbon of 4.3 g kg^{-1} than under conventional tillage (3.8 g kg^{-1}). Among the treatments, when averaged over tillages, 4 t compost + 2 t gliricidia loppings recorded significantly highest amount of particulate organic carbon content of 4.5 g kg^{-1} at surface depth while under subsurface depth, 4 t compost + 20 kg N through urea recorded the highest particulate organic carbon content of 4.0 g kg^{-1} respectively.

Total carbon in the soils ranged from 7.9 to 9.2 g kg^{-1} and 9.0 to 10.5 g kg^{-1} at surface depth under conventional and minimum tillage respectively. At the subsurface depth of 5-20 cm, it ranged from 7.9 to 9.2 g kg^{-1} under conventional tillage and 8.8 to 10.1 g kg^{-1} under minimum tillage. When averaged over the INM treatments, minimum tillage had significant influence on total organic carbon contents in the soil which maintained the total C level to the extent of 9.7 g kg^{-1} and 9.5 g kg^{-1} at surface and subsurface depths respectively. These levels were significantly higher than those under conventional tillage. The conjunctive nutrient use treatments also showed a significant influence on the total carbon content in the soil under both the surface and subsurface depths. Among all the treatments, 4 t compost + 2 t gliricidia loppings recorded significantly highest total carbon content of 9.8 and 9.7 g kg^{-1} under surface and sub surface depths respectively.

Table 161: Long-term effect of tillage and INM treatments on soil carbon pools under sorghum- green gram system

Tillage	Treatments equivalent to 40 kg N ha^{-1}	Total organic carbon g kg^{-1}		Inorganic carbon g kg^{-1}		MBC μg g^{-1} of soil		0.01 N $KMnO_4$ Oxidizable carbon (Labile carbon) μg g^{-1} of soil		Particulate organic carbon g kg^{-1}		Total carbon g kg^{-1}	
	Depth in cm→	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20
CT	T1 = Control	4.3	4.3	3.5	3.6	96.4	90.6	241.8	241.0	3.1	3.2	7.9	7.9
	T2 = 40 kg N through urea	5.6	5.3	3.6	3.4	173.9	164.4	260.0	280.0	3.9	3.5	9.2	8.7
	T3 = 4 t compost + 20 kg N through urea	5.8	5.7	3.4	3.5	164.6	150.1	285.4	278.1	4.0	3.7	9.2	9.2
	T4 = 2 t Gliricidia loppings + 20 kg N through urea	5.5	5.3	3.4	3.6	143.5	125.0	317.7	297.3	3.8	3.4	8.9	8.9
	T5 = 4 t compost + 2 t gliricidia loppings	5.9	5.7	3.2	3.5	170.8	146.5	292.1	277.4	4.2	3.1	9.1	9.2
MT	T1 = Control	5.4	5.4	3.6	3.4	97.6	96.2	257.7	257.5	4.0	3.7	9.0	8.8
	T2 = 40 kg N through urea	5.7	5.6	3.7	3.5	174.8	150.5	280.5	265.9	4.1	4.3	9.3	9.1
	T3 = 4 t compost + 20 kg N through urea	6.3	6.0	3.5	3.5	174.5	151.4	304.1	297.0	4.3	4.2	9.8	9.6
	T4 = 2 t Gliricidia loppings + 20 kg N through urea	6.5	6.3	3.4	3.6	128.1	124.4	302.9	251.2	4.1	3.1	9.9	10.0
	T5 = 4 t compost + 2 t gliricidia loppings	6.9	6.7	3.6	3.4	174.5	153.4	307.3	275.5	4.8	4.5	10.5	10.1
	LSD (P = 0.05)												
	Between tillage means	*0.22*	*0.27*	*0.15*	*NS*	*NS*	*NS*	*NS*	*NS*	*0.34*	*NS*	*0.27*	*0.35*
	Between treatment means	*0.26*	*0.28*	*0.15*	*NS*	*8.3*	*4.41*	*22.5*	*NS*	*0.49*	*0.41*	*0.34*	*0.34*
	Between two treatment means at same tillage	*0.37*	*0.40*	*NS*	*NS*	*NS*	*6.24*	*NS*	*NS*	*NS*	*0.58*	*0.48*	*NS*
	Between two treatment means at same or different treatments	*0.35*	*0.38*	*NS*	*NS*	*NS*	*6.26*	*NS*	*NS*	*NS*	*0.73*	*0.45*	*NS*

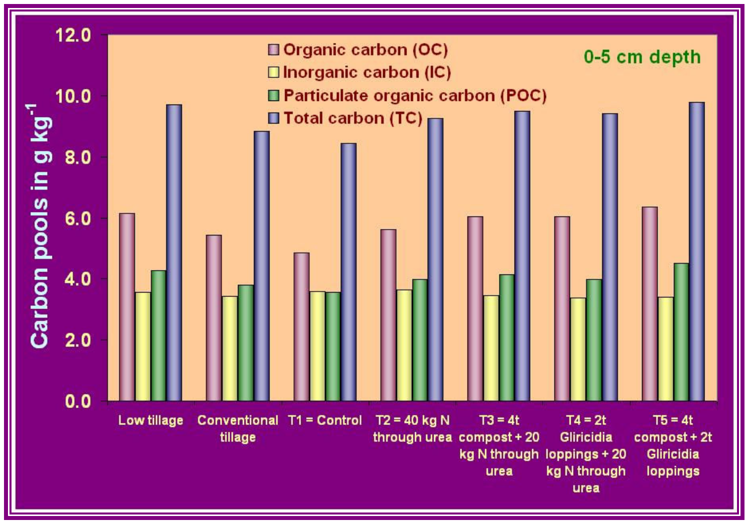

Fig 141: Long term effect of tillage and INM treatments on soil carbon pools 0-5 cm depth under sorghum –green gram system

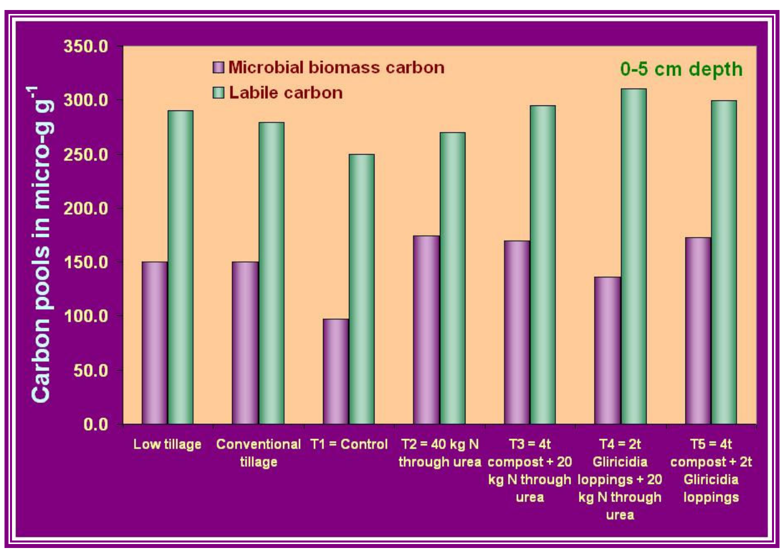

Fig 142: Long-term effect of tillage and INM treatments on soil carbon pools 0-5 cm depth

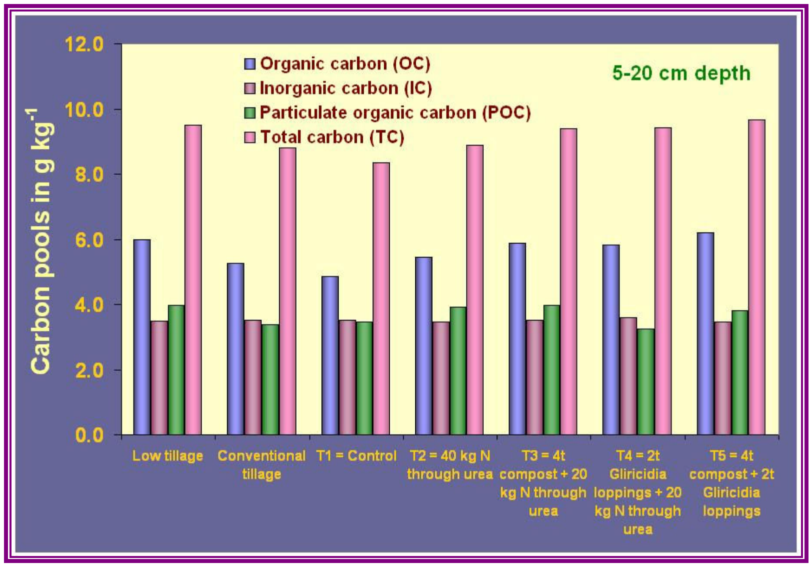

Fig 143: Long term effect of tillage and INM treatments on soil carbon pools at 5-20 cm depth

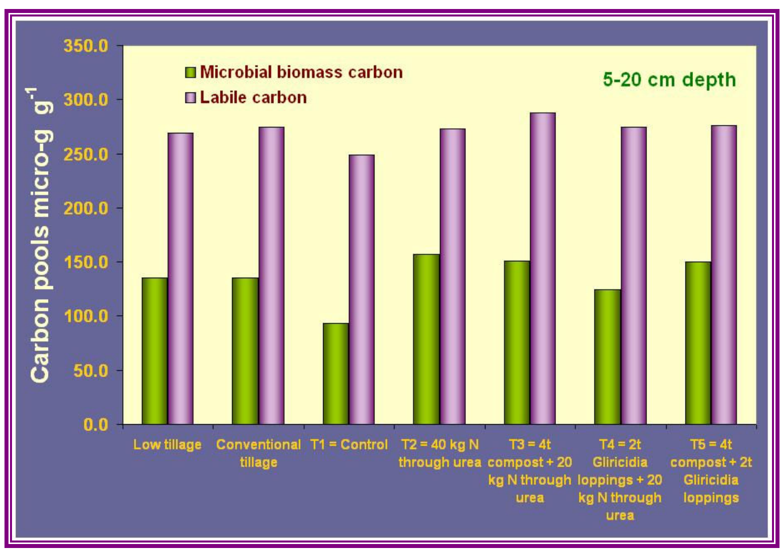

Fig 144: Long term effect of tillage and INM treatments on soil carbon pools 5-20 cm depth

4.2.35.8. Enzymatic activity as influenced by INM and tillage practices under sorghum- green gram strip cropping (during 2006)

The data on enzymatic activity as influenced by INM and tillage practices is presented in Table 162. Dehydrogenase activity in the soil varied from 1.75 to 4.14 and 1.56 to 4.79 µg TPF g^{-1} hr^{-1} under conventional and minimum tillage respectively at surface depth. In the subsurface depth, the corresponding values varied from 1.55 to 3.90 and 1.22 to 4.80 µg TPF g^{-1} hr^{-1} respectively. Minimum tillage proved significantly quite superior in influencing the dehydrogenase activity in the soils compared to conventional tillage. In minimum tillage, the dehydrogenase activity was 3.83 and 3.34 µg TPF g^{-1} hr^{-1} under surface and subsurface depths respectively. Among the treatments, when averaged over the tillage, 2 t Gliricidia loppings + 20 kg N through urea recorded significantly highest dehydrogenase activity of 4.5 µg TPF g^{-1} hr^{-1}which was at par with 4 t compost + 2 t gliricidia loppings (4.3 µg TPF g^{-1} hr^{-1}) at surface depth. While under subsurface depth, 4 t compost + 2 t gliricidia loppings recorded significantly highest dehydrogenase activity of 4.05 µg TPF g^{-1} hr^{-1} which was at par with 4t compost + 20 kg N through urea (3.97 µg TPF g^{-1} hr^{-1}). Among the interaction effects, 2 t Gliricidia loppings + 20 kg N through urea under minimum tillage recorded highest dehydrogenase activity (4.79 µg TPF g^{-1} hr^{-1}) at surface depth while under subsurface depth, minimum tillage +2 t Gliricidia loppings + 20 kg N through urea recorded highest dehydrogenase activity (4.80 µg TPF g^{-1} hr^{-1}).

Another important enzyme studied was arylsulphatase. The activity of arylsulphatase in the soils ranged from 43.1 to 57.4 µg PNP g^{-1} hr^{-1} under conventional tillage and 43.7 to 59.1 µg PNP g^{-1} hr^{-1} under minimum tillage at surface depth. The corresponding values at the subsurface depth varied from 38.3 to 56.7 µg PNP g^{-1} hr^{-1} and 31.8 to 54.4 µg PNP g^{-1} hr^{-1} under conventional and minimum tillages respectively. Tillage did not play any significant role in influencing the arylsulphatase activity at both surface and subsurface depths of the soil. However, the conjunctive nutrient use treatments significantly influenced the arylsulphatase activity where 4 t compost + 20 kg N through urea recorded significantly highest arylsulphatase activity of 57.71 µg PNP g^{-1} hr^{-1} at surface depth, while 2 t Gliricidia loppings + 20 kg N through urea showed significantly highest arylsulphatase activity (55.70 µg PNP g^{-1} hr^{-1}) at subsurface depth.

Table 162: Effect of INM and tillage treatments on enzyme activity under sorghum-green gram strip cropping during 2006

Tillage	INM Treatments equal to 20 kg N ha^{-1}	Dehydrogenase µg TPF g^{-1} hr^{-1}		Aryl sulphatase µg PNP g^{-1} hr^{-1}	
	Depth in cm→	0-5	5-20	0-5	5-20
CT	T1 = Control	1.75	1.57	43.4	38.3
	T2 = 40 kg N through urea	2.50	1.55	43.1	42.6
	T3 = 4 t compost + 20 kg N through urea	3.99	3.90	57.4	49.9
	T4 = 2 t Gliricidia loppings + 20 kg N through urea	4.14	3.54	55.8	53.8
	T5 = 4 t compost + 2 t gliricidia loppings	3.97	3.31	46.9	56.7
MT	T1 = Control	1.56	1.22	45.4	37.7
	T2 = 40 kg N through urea	4.18	3.25	43.7	31.8
	T3 = 4 t compost + 20 kg N through urea	4.10	4.06	58.0	49.1
	T4 = 2 t Gliricidia loppings + 20 kg N through urea	4.79	3.39	51.2	46.8
	T5 = 2t Gliricidia loppings + 20 kg N through urea	4.54	4.80	59.1	54.4
	Between tillage means	0.51	0.31	NS	NS
	Between treatment means	0.51	0.47	4.66	8.19
	Between two treatment means at same tillage	0.73	0.66	6.59	NS
	Between two treatment means at same or different treatments	0.70	0.61	6.55	NS

* In case of green gram doses of above treatments were reduced to equivalent to 20 kg N ha^{-1}

4.2.36. Objective 3: To study the response of sorghum - cowpea system to graded levels of surface residue application iunder minimum tillage in Alfisol and effects on carbon storage

During the Fellowship period, a new field experiment was initiated during June 2005 at Hayathnagar Research Farm (17°18′ N latitude, 78°36′ E longitude and an elevation of 515 m above mean sea level) of Central Research Institute for Dryland Agriculture, Hyderabad, India. The farm represents a semi-arid tropical region with hot summers and mild winters and a mean annual temperature of 25.7^{o}C. The mean maximum temperature during March to May varies from 35.6 ^{o}C to 38.6 ^{o}C. Mean minimum temperature during the winter months (December, January and February) ranges from 13.5 to 16.8 ^{o}C. Mean annual rainfall is 746 mm and accounts for approximately 42% of annual potential evapotranspiration (1754 mm). Nearly 70% of the total precipitation is received during the southwest monsoon season (June to September). Soils in the experimental field belong to Hayathnagar soil series (Typic Haplustalf). These soils have a sandy surface layer, with increasing clay content in the sub soil. The prime focus of the study was to give maximum opportunity to soil to store / sequester more and more carbon so that its sequestration potential could be assessed over a period of time. Considering this fact, the necessity of conservation agricultural practices such as 'no tillage' and application of residues on the surface and retaining the crop stubbles after the harvest of the crop was felt. The hypothesis in the experimentation was that, despite experiencing the constraints viz., coarse texture, extreme temperature variations, hot summers, scarce rainfall and low cropping intensity, i) if crop residue is recycled back in adequate amount as surface application, ii) crops are grown without tilling the soil, iii) application of adequate amount of nutrients, iv) effectively controlling weeds, v) allowing crop stubbles standing on the surface of the soil, vi) protecting the residue from burning and grazing, vii) protecting the loss of clay and soil organic matter from water erosion, can enhance organic carbon content in these soils to a considerable extent over a period of time . The objective is long term objective

Considering the above, the experiment was initiated with T1 = Control, T2 = 2 t ha^{-1} Sorghum stover, T3 = 6 t ha^{-1} Sorghum stover, and T4 = 8 t ha^{-1} Sorghum stover in a randomized block design with three replications with sorghum (CSH-9) as the test crop. The crop was planted using 'no-tillage' approach employing tractor drawn seed planter or by using a non inversion typr plough depending upon the situation. Different levels of sorghum residues were applied as surface application after 3 weeks of crops germination every year. Nitrogen and phosphorus were applied uniformly to all the plots @ 60 Kg N ha^{-1} and 30 kg P_2O_5 ha^{-1} respectively. The weeds were controlled manually. The initial soil characteristics of the experimental site are presented in Table 163.

Table 163: Initial characteristics of the experimental site

Sno	Parameters	
1	pH	6.52
2	EC (dS m^{-1})	1.30
3	Organic carbon (g kg^{-1})	5.60
4	Available Nitrogen (kg ha^{-1})	120.0
5	Available Phosphorus (kg ha^{-1})	16.1
6	Available Potassium (kg ha^{-1})	230.4
7	Exchangeable Calcium (cmol kg^{-1})	7.63
8	Exchangeable Magnesium (cmol kg^{-1})	2.15
9	Available Sulphur (μg g^{-1})	5.30
10	DTPA extractable Zn (μg g^{-1})	0.56
11	DTPA extractable Fe (μg g^{-1})	2.33
12	DTPA extractable Cu (μg g^{-1})	0.98
13	DTPA extractable Mn (μg g^{-1})	10.2
14	DTPA extractable B (μg g^{-1})	0.56
15	Dehydrogenase assay (μg TPF $hr^{-1}g^{-1}$)	3.12
16	Labile carbon (mg kg^{-1})	269.2
17	Bulk density (Mg m^{-3})	1.79
18	Mean weight diameter (mm)	0.21
19	Particle density	2.12

4.2.36.1. Effect on Crop yields

During the first year, the crop was seeded during last week of June because of delay in monsoon for atleast 3 ½ weeks. Crop also suffered Striga (sorghum root parasite weed) attack. Sorghum grain yields in the first year of the experiment varied from 1396 to 1549 kg ha^{-1} and did not show much significant effect of different treatments. However, application of 6 t ha^{-1} of sorghum stover recorded the highest grain yield of 1549 kg ha^{-1} followed by application of 2t ha^{-1} of sorghum stover (1501 kg ha^{-1}). Since, this experiment has been planned on long-term basis to sequester/ store more and more carbon by making the soil as a sink, the intensive soil studies have been planned in the future. The CO_2 fluxes emitted through soil respiration was also periodically assessed. The details are presented in the next section.

During the second year, the sorghum crop during 2005 was harvested by leaving behind stubbles to the height of 35 cm. After the harvest of sorghum, herbicide sprays were practiced during the summer months to control the weeds. During kharif season of 2006, sunflower crop (Ganga

Kaveri- GK 2002 and KBSH-1) sown in 1st week of June and subsequently on 3rd week of June could not be established due to initial dry spells and compacted surface layer under zero tillage.

To generate biomass by capitalizing the remaining part of the season, short duration legume crops viz., cowpea (C-152) (kharif) and horsegram (CRHG – 17) (Rabi) were sown during 4th week of July and 4th week of October respectively, under zero tillage conditions with 50 x 10 cm and 30 x 10 cm spacing respectively. The biomass of cowpea crop was harvested during 4th week of September. After recording the weight, it was left in the field on surface for further recycling. In case of horse gram, pods were harvested at maturity during 4th week of December and the remaining biomass was left in the field after harvest (Table 164 & Fig 145). Due to irregular rainfall, compaction and weed growth in in reduced minimum tillage, the biomass yields of both the crops were also severely affected. In order to study the influence of surface residue application under conservation tillage on carbon pools viz., microbial biomass carbon (MBC), 0.01 N $KMnO_4$ extractable labile C ($KMnO_4$ - LC), particulate organic carbon (POC), Inorganic C (IC), total organic carbon (TOC), soil samples from two depths (0-5, 5-20) were collected after the harvest of the 1st crop of sorghum (2005) and were analyzed using standard procedures. The salient findings of the study were as follows.

Effect of surface crop residue application on the crop yields

- The yields of above ground dry biomass in cowpea varied from 228 to 319 kg ha^{-1}. The highest yield of above ground dry biomass was recorded under application of 4 t ha^{-1} of sorghum stover, which was at par with 2 t ha^{-1} of sorghum stover (312 kg ha^{-1}). However, the application of sorghum stover above 4 t ha^{-1} did not show any significant increase in the above ground biomass yields and were even lesser than the control. This may be attributed to the ill effect of immobilization occurred due to application of higher rates of sorghum stover in early years .

- The pod yield of horsegram raised as a subsequent crop after cow pea, was significantly influenced and varied from 322 to 468 kg ha^{-1}. Horse gram grain and husk yields were also significantly influenced by different residue levels and ranged from 196 to 290 kg ha^{-1} and 126 to 179 kg ha^{-1} respectively.

- Interestingly, sorghum stover applied @ 6 t ha^{-1} did not adversely affect the yield of the second crop and recorded the highest horse gram pod yield (468 kg ha^{-1}), grain yield (290 kg ha^{-1}) and husk yield (179 kg ha^{-1}). This treatment was followed by the residue applied @ 4 t ha^{-1}.

- However, the yield levels, in general, were low. This may be attributed to ii) erratic rainfall, weed growth and less water intake in the profile under minimum tillage. Further, the less aeration of the root zone due to zero tillage also might have affected the plant growth.

Table 164: Yields (kg ha^{-1}) of cowpea and horse gram as influenced by residue application during 2006

Sno.	Treatments	Cowpea above ground dry biomass	Cowpea below ground dry biomass	Horse gram pod yields	Horse gram grain yields	Horse gram husk yields
1	T1- Control	290	267	322	196	126
2	T2-2t/ha of sorghum stover	312	249	336	210	127
3	T3- 4t/ha of sorghum stover	319	275	348	210	137
4	T4-6t/ha of sorghum stover	228	225	468	290	179
	CV @ 0.05 level	*45.7*	*NS*	*56.57*	*27.16*	*35.13*

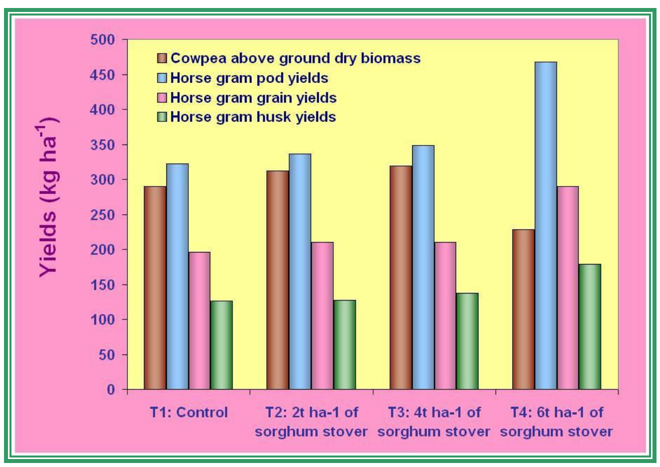

Fig 145: Cowpea and horse gram yields as influenced by residue application

During the third year, the sorghum grain yields varied from 1878 to 2242 kg ha^{-1} across the treatments (Table 165 & Fig 146). Surface application of 6 t ha^{-1} of sorghum residue recorded significantly highest sorghum grain yield of 2242 kg ha^{-1} which was at par with application of 4 t ha^{-1} of sorghum residue (2020 kg ha^{-1}). The increase in sorghum grain yield over control under these two treatments was 19.8 % and 7.98% respectively. While application of sorghum residue @ 2 t ha^{-1} could increase the sorghum grain yield by 0.51% only which was very negligible. The husk yields as well as the dry stover yields followed the similar trend. The highest yields of husk (1057 kg ha^{-1}) and dry stover (6197 kg ha^{-1}) were also recorded under application of 6 t ha^{-1} of sorghum residue. The harvest index was also found highest under 6 t ha^{-1} of sorghum residue (0.27). The beneficial effects of surface applied residues could be on several accounts such as reducing the water losses due to evaporation, keeping the soil temperature low, enhancing the microbial activity, more recycling of nutrients, protecting the soil from water erosion by way of intercepting the rain drops, etc.

Table 165: Effect of crop residue application on yields of sorghum crop (SPV 462) during the year 2007

Sno.	Treatments	Grain yield kg ha^{-1}	% increase in grain yield over control	Husk yield kg ha^{-1}	Dry stover yield kg ha^{-1}	Harvest Index
1.	T1- Control	1878	--	851	6460	0.23
2	T2-2 t ha^{-1} of sorghum residue	1882	0.51	857	5494	0.26
3	T3- 4 t ha^{-1} of sorghum residue	2020	7.98	893	6456	0.24
4	T4- 6 t ha^{-1} of sorghum residue	2242	19.79	1057	6197	0.27
	CV @ 0.05 level	239.4	--	125.4	457.3	0.02

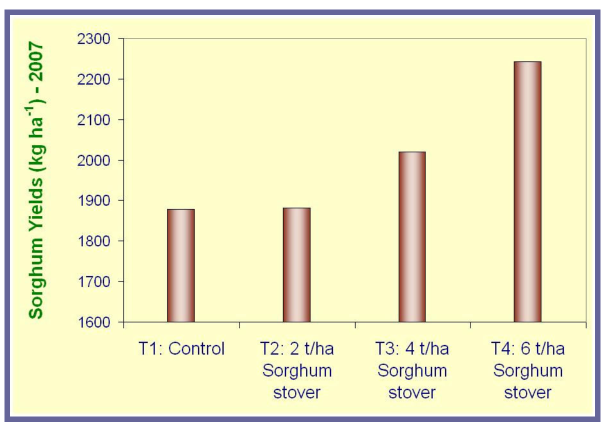

Fig 146: Influence of surface application of graded levels of crop residue on sorghum grain yields

Table 166: Effect of application of graded level of crop residue as surface application + 60 kg N on crop yields under no till conditions in rainfed Alfisol

Sno.	Treatments	Sorghum grain yields	Horse gram Yields	Sorghum grain Yields	Cowpea Grain yield kg ha^{-1}
		2005	2006	2007	2008
1.	T1- Control	1473	196.1	1878	348
2	T2-2 t ha^{-1} of sorghum residue	1501	210.0	1882	420
3	T3- 4 t ha^{-1} of sorghum residue	1549	209.7	2020	543
4	T4- 6 t ha^{-1} of sorghum residue	1396	289.8	2242	466
	CD @ 0.05				89.5

During the fourth year of the study (2008), the effect of graded levels of surface application of crop residue on cowpea (C 152) crop yield was studied (Table 167 & Fig 147). Residue application significantly increased the cowpea grain yield with sorghum residue applied as surface mulch @ at 4t ha^{-1} in combination with N @ 30 kg ha^{-1} under minimum tillage conditions. The increase in grain yield of cowpea with residue application @ 2, 4 and 6 t ha^{-1} was to the tune of 20.7, 56.0 and 33.9% respectively over control. The influence on C storage in relation to inputs in profile will be rigorously monitored after 5th year of the study and in subsequent years.

Table 167: Effect of crop residue application on yields of cowpea (C 152) crop during the year 2008

Sno.	Treatments	Grain yield kg ha^{-1}	% increase in grain yield over control
1.	T1- Control	348	-
2	T2-2 t ha^{-1} of sorghum residue	420	20.69
3	T3- 4 t ha^{-1} of sorghum residue	543	56.03
4	T4- 6 t ha^{-1} of sorghum residue	466	33.90
	LSD (p =0.05 level	89.5	-

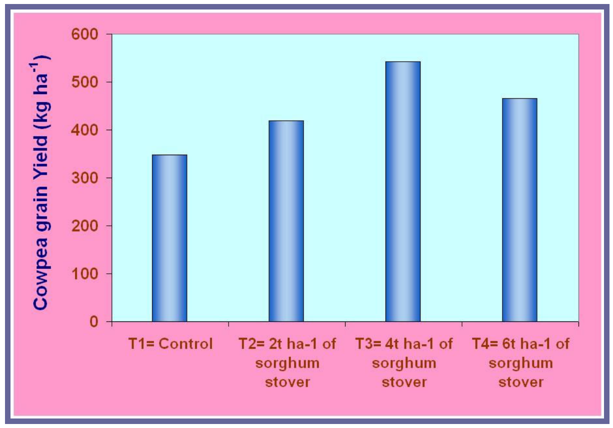

Fig 147: Effect of sorghum residue application on yields of cowpea (C 152) crop during the year 2008

4.2.36.2. Effect of surface crop residue application on the carbon pools

During the first year, in order to study the influence of surface residue application under conservation tillage on carbon pools viz., microbial biomass carbon (MBC), 0.01 N $KMnO_4$ extractable labile C ($KMnO_4$ - LC), particulate organic carbon (POC), Inorganic C (IC), total organic carbon (TOC), soil samples from two depths (0-5, 5-20) were collected after the harvest of the 1st crop of sorghum (2005) and were analyzed using standard procedures. The salient findings of the study were as follows.

- Based on the data generated after the 1st year of the experiment, it was observed that, except microbial biomass carbon, the other pools were not significantly influenced by the application of various levels of sorghum residues + 60 kg N ha^{-1} applied to previous crops + minimum tillage at both surface (0-5 cm) and sub-surface (5-20 cm) depths (Table 168 to 169 & Fig 148 to 149).
- Total Organic carbon (TOC) ranged from 4.2 to 5.2 g kg^{-1} at 0-5 cm depth and 3.8 to 4.8 g kg^{-1} at 5-20 cm depth. Whereas, inorganic carbon in the corresponding soil depths varied between 2.3 to 2.6 g kg^{-1} and 2.3 to 2.6 g kg^{-1} respectively. Interestingly, organic carbon content decreased in the lower depth while inorganic carbon was relatively higher.
- Microbial biomass carbon (MBC) is an important indicator of soil quality and is a measure of the living component of soil organic matter, except macro fauna and plant roots. In the present study, it ranged from 89.47 to 177.11 µg g^{-1} of soil at 0-5 cm depth and 76.93 to 167.83 µg g-1 of soil at 5-20 cm depth. Among the residue levels applied to the first crop (sorghum), application of 6 t ha^{-1} of sorghum stover recorded significantly highest

microbial biomass carbon of 177.11 and 167.83 μg g^{-1} of soil at 0-5 and 5-20 cm respectively. The content of MBC in plots amended with 2 and 4 t ha^{-1} of residue almost remained same.

- The 0.01 N $KMnO_4$ oxidizable organic carbon is considered as a good measure of labile carbon or active carbon in soil. In this study, it ranged from 309.39 to 344.34 and 299.16 and 340.39 μg g^{-1} of soil at 0-5 and 5-20 cm depths respectively, and was not significantly affected by the management treatments.
- Similarly, particulate organic carbon (POC) and total carbon (TC) in the soils were also not significantly affected by the management treatments. However POC contents varied between 3.1 to 3.8 g kg^{-1} at 0-5 cm depth and 2.8 to 3.4 g kg^{-1} at 5-20 cm depth. Data indicated that POC content was relatively higher in surface layer than sub surface layer. It constituted about 63.49 to 74.49 and 48.51 to 77.84 % of TOC in surface and sub surface respectively.
- The extent of TC was to the tune of 6.5 to 7.8 and 6.3 to 7.4 g kg^{-1} at 0-5 and 5-20 cm depths respectively. Except inorganic carbon, all other carbon pools tended to decrease in sub-surface soil layer.

Table 168: Influence of residue application on different carbon pools at surface and sub- surface soil layers

Sn o.	Treatments	Organic carbon g kg^{-1}		Inorganic carbon g kg^{-1}		Microbial biomass carbon μg g^{-1} of soil	
		OC		Inorg. C		MBC	
	Depth in cm →	0-5	5-20	0-5	5-20	0-5	5-20
1	T1- Control	4.2	3.8	2.3	2.6	89.5	76.9
2	T2-2t ha^{-1} of sorghum stover	4.7	4.5	2.3	2.5	107.4	106.0
3	T3- 4t ha^{-1} of sorghum stover	4.8	4.5	2.2	2.3	109.0	105.0
4	T4-6t ha^{-1} of sorghum stover	5.2	4.8	2.6	2.6	177.1	167.8
	LSD (p= 0.05)	NS	NS	NS	NS	12.4	19.7

Table 169: Influence of residue application on different carbon pools at surface and sub- surface soil layers

Sn o.	Treatments	0.01 M $KMnO_4$ Oxidizable carbon (Labile carbon) μg g^{-1} of soil		Particulate organic carbon g kg^{-1}		Total carbon g kg^{-1}	
		Oxi. C		POC		Total C	
	Depth in cm →	0-5	5-20	0-5	5-20	0-5	5-20
1	T1- Control	309.4	299.2	3.1	2.8	6.5	6.3
2	T2-2t ha^{-1} of sorghum stover	322.4	305.4	3.3	3.2	7.0	7.0
3	T3- 4t ha^{-1} of sorghum stover	330.6	321.5	3.4	3.3	7.1	6.5
4	T4-6t ha^{-1} of sorghum stover	344.3	340.4	3.8	3.4	7.8	7.4
	LSD (p= 0.05)	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

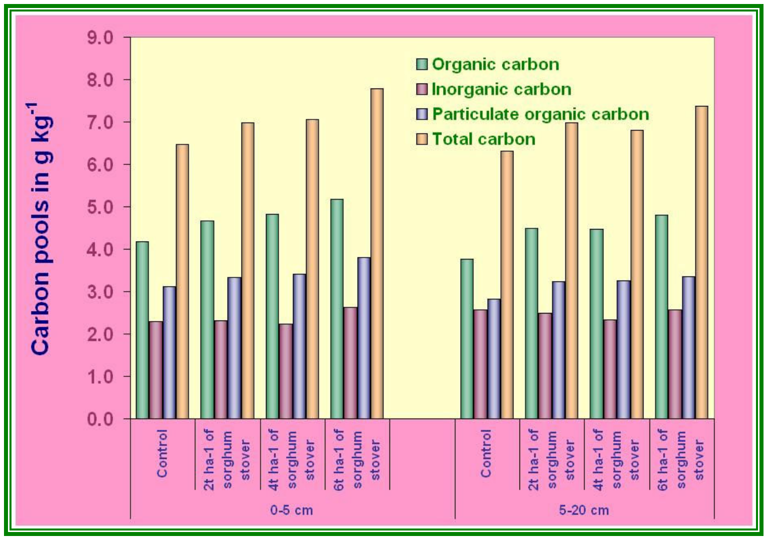

Fig 148: Influence of residue application on four different carbon pools at surface and sub- surface soil layers

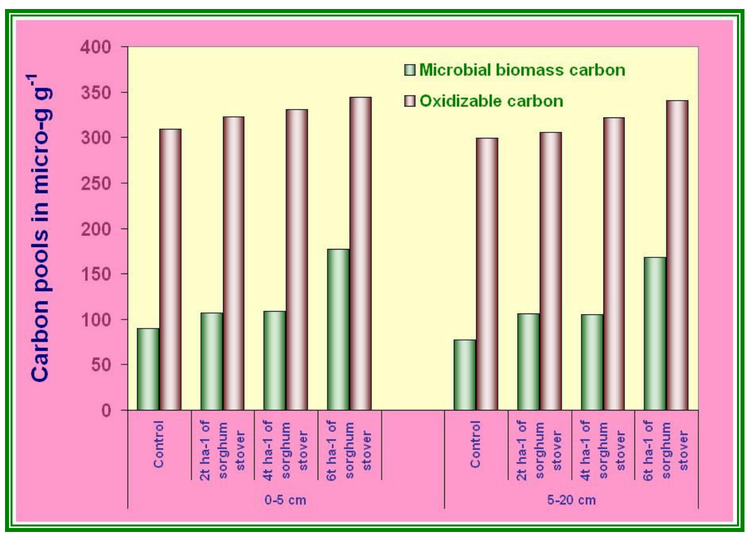

Fig 149: Influence of residue application on two different carbon pools at surface and sub- surface soil layers

4.2.36.3. Effect of residue application on soil enzyme activity

The influence of surface residue application under minimum tillage on activity of four types of enzyme viz., dehydrogenase, arylsulphatase, urease and phosphatase was also studied after the second year in these soils. It is well established that the specificity and integrative nature of soil enzyme activity provide a potential basis for the use of soil enzyme activity as an indicator of certain function in soil. Hence, enzyme activity becomes one of the important and sensitive indicators of biological soil health. Hence, in the present study, activities of enzyme viz., dehydrogenase, arylsulphatase (Tabatabai and Bremner, 1970a) and urease (Tabatabai and Bremner, 1972b) was studied in these soils and the data are presented in Table 170. Activities of all the enzymes studied were found to be significantly influenced by the management treatments and the data clearly indicated a reduction in the activity of these enzymes in the lower depth (5-20 cm) of the soil compared to the surface 0-5 cm depth.

a) Dehydrogenase

Dehydrogenase activity in these soils ranged between 1.44 to 2.49 μg $TPFg^{-1}$ hr^{-1} at 0-5 cm depth and 1.28 to 1.74 μg $TPFg^{-1}$ hr^{-1} at subsurface depth. Application of 6 t ha^{-1} of sorghum stover recorded the highest dehydrogenase assay of 2.49 at 0-5 cm depth, which was followed by the application of 4 t ha^{-1} of sorghum stover while the control plot recorded the lowest assay. At 5-20 cm depth also application of 6 t ha^{-1} of sorghum stover recorded the highest dehydrogenase activity of 1.74 μg TPF g^{-1} hr^{-1}.

b) Arylsulphatase

Sulphatase enzyme has been reported to help in releasing plant available $S0_4$ from organic matter. There are several sulphatases present in nature. Most of them have been classified according to the type of organic sulphate esters they hydrolyze, with the following main groups recognized: aryl sulphatases, alkylsulphatases, steroid sulphatases, glucose sulphatases, chondrosulphatases and myrosulphatases (Fromageot, 1950; Roy, 1960). Arylsulphatase (arylsulphate sulphohydrolase) is the enzyme that catalyses the hydrolysis of an arylsulphate anion by fission of the O-S bond (Spencer, 1958).The reaction goes as follows.

$$R \cdot OSO_3^- + H2O = R \cdot OH + H^+ + SO_4^{2-}$$

In the present study arylsulphatase activity in the soils varied from 100.62 to 174.41 and 76.0 to 139.6 μg PNP g^{-1} hr^{-1} at surface and subsurface depths respectively. At 0-5 cm depth, significantly highest arylsulphatase activity of 174.41 μg PNP g^{-1} hr^{-1} was recorded under application of 6 t ha^{-1} of sorghum stover followed by 4 t ha^{-1} of sorghum stover application. While under subsurface depth, 4 t ha^{-1} of sorghum stover recorded highest arylsulphatase activity of 139.6 μg PNP g^{-1} hr^{-1}, which was followed by 6 t ha^{-1} of sorghum stover (127.1 μg PNP g^{-1} hr^{-1}). Reason of lower activity at higher residue level could not be understood.

c) Urease

Urease activity in these soils ranged from 19.83 to 62.01 μg NH4 g^{-1} hr^{-1} and 14.53 to 53.55 μg NH4 g^{-1} hr^{-1} at 0-5 cm and 5-20 cm depths respectively. Unlike arylsulphatase, the activity of urease recorded a similar trend to that of dehydrogenase activity, where 6 t ha^{-1} of sorghum stover recorded the highest urease activity of 62.01 and 53.55 μg NH4 g^{-1} hr^{-1} at 0-5 and 5-20 cm depths respectively, which was followed by 4 t ha^{-1} of sorghum stover.

Table 170: Enzymatic activity at surface and sub-surface soil as influenced by residue application

Sno.	Treatments	DHA μg TPF g^{-1} hr^{-1}		Arylsulphatase μg PNP g^{-1} hr^{-1}		Urease μg NH_4 g^{-1} hr^{-1}	
	Depth in cm →	0-5	5-20	0-5	5-20	0-5	5-20
1	T1- Control	1.44	1.36	100.62	76.0	19.83	14.53
2	T2-2t ha^{-1} of sorghum stover	1.47	1.45	135.64	96.9	26.67	25.03
3	T3- 4t ha^{-1} of sorghum stover	2.29	1.28	151.28	139.6	34.83	35.30
4	T4-6t ha^{-1} of sorghum stover	2.49	1.74	174.41	127.1	62.01	53.55
	LSD (p=0.05)	*0.68*	*0.31*	*22.19*	*26.18*	*4.23*	*8.37*

During the year 2007, the effect of graded levels of surface application of crop residue on sorghum (SPV 462) crop yield and the activity of some predominant enzymes viz., acid phosphatase and alkaline phosphatase have been presented (Sharma, 2007).

d) Phosphatase enzymes

This group of enzymes phosphomonoesterases (acid and alkaline phosphatases) catalyzes the hydrolysis of both esters and anhydrides of H_3PO_4 (Schmidt and Laskowski, 1961). As reported by Florkin and Stotz, (1964), these enzymes have been classified into five major groups viz., Phosphoric monoester hydrolases, phosphoric diester hydrolases, triphosphoric monoester hydrolases, enzymes acting on phosphoryl–containing anhydrides, and enzymes acting on P-N bonds such as the phosphoamidase. Among this group of enzymes, phosphomonoesterases, acid phosphotase (orthophosphoric monoester phosphohydrolase, EC 3.1.3.2) and alkaline phosphotase (orthophosphoric monoester phosphohydrolase, EC 3.1.3.1) have been studied extensively. The enzymes are classified as acid and alkaline phosphatases because they show their optimum activities in acid and alkaline ranges, respectively. Because of the importance of these enzymes in soil organic P mineralization and plant nutrition, considerable literature has accumulated on phosphomonoesterases in soils (Speir and Ross, 1978).

The general equation of the reaction catalyzed by acid and alkaline phosphatase can be given as follows:

$$R-O-\underset{\displaystyle O^-}{\overset{\displaystyle O}{\overset{||}{\underset{|}{P}}}}-O^- + H_2O \rightarrow R.OH + HO-\underset{\displaystyle O^-}{\overset{\displaystyle O}{\overset{||}{\underset{|}{P}}}}-O^-$$

Studies by Eivazi and Tabatabai (1977) and Juma and Tabatabai (1977, 1978) show that acid phosphotase is predominant in acid soils while alkaline phosphatase is predominant in alkaline soils. The inverse relationship between phosphotase activity and soil pH suggests that, either the rate of synthesis and release of this enzyme by soil microorganisms or the stability of these enzymes is related to soil pH. Since higher plants are devoid of alkaline phosphatase activity (Dick et al., 1983; Juma and Tabatabai, 1988 a, b, c), the alkaline phosphatase activity in soils seems to be derived totally from microorganisms.

In the present study, acid phosphatases and alkaline phosphatases were assayed by mixing 1 gm of soil (< 2mm) with 0.2 ml of toluene, 4 ml of modified universal buffer (pH 6.5 for acid phoshphatases and pH 11 for alkaline phosphatases) and 1 ml of 0.025 M *p*-nitrophenyl phosphate (substrate). The flask was swirled for few seconds to mix the contents. After incubation for 60 min at 37 ^{o}C, the enzyme reaction was stopped by adding 1 ml 0.5 M $CaCl_2$ and 4 ml of 0.5 M NaOH. The contents were centrifuged at 4000 rpm for 10 min and the absorbance was measured at 410 nm. Control sample was also given the same treatment. However the addition of *p*-nitrophenyl phosphate was made after the addition of 0.5 M $CaCl_2$ and 0.5 M NaOH. The calculated enzyme activity was expressed in µg of *p*-nitrophenol released per gram per hour (Tabatabai and Bremner, 1969; Eivazi and Tabatabai, 1977).

Acid phosphatases (Ac-P) estimated in these soils ranged from 179.8 to 549.5 and 128.1 to 458.2 µg PNP g^{-1} hr^{-1} at 0-5 cm and 5-20 cm depths respectively (Table 171) across the treatments. The significant highest Ac-P activity of 549.5 and 458.2 µg PNP g^{-1} hr^{-1} was recorded under application of 6 t ha^{-1} sorghum residue at surface depth (0.5 cm) and sub-surface depth (5.20 cm) followed by 4 t ha^{-1} of sorghum residue application. Application of 6 t ha^{-1} sorghum residue accounted for an increase of 205.57 % and 257.69 % over control at 0-5 cm and 5-20 cm depths respectively. The plots which received 4 t ha^{-1} and 2 t ha^{-1} sorghum residues showed an increase of 150.4% and 189.5 %, 139.0 % and 172.3 % at surface and subsurface depths respectively. The mean value of 503.9 µg PNP g^{-1} hr^{-1} of Ac-P activity irrespective of depth was found to be highest under application of 6 t ha^{-1} sorghum residue followed by 4 t ha^{-1} of sorghum residue application.

However, the mean value of 402.3 µg PNP g^{-1} hr^{-1} of AC-P activity irrespective of treatment was found to be highest in 0-5 cm depth showing decreasing trend with depth (Fig 150).

The alkaline phosphatase activity (Alk-P) showed a trend similar to Ac-P activity. The significantly highest Alk-P activity of 400.3 and 328.0 µg PNP g^{-1} hr^{-1} was recorded under application of 6 t ha^{-1} sorghum residue followed by 4 t ha^{-1} of sorghum residue application at 0- 5 cm and 5- 20 cm depths respectively (Table 171). Application of 6 t ha^{-1} sorghum residue recorded an increase of 376.2 % and 514.7 % over control in 0-5 cm and 5-20 cm depths respectively. Application of 4 t ha^{-1} of sorghum residue recorded an increase of 183.8 % and 232.5 % whereas 2 t ha^{-1} accounted for an increase of 38.7 and 91.3 % over control at 0-5 cm and 5-20 cm respectively. The significantly highest mean Alk-P activity of 364.1 µg PNP g^{-1} hr^{-1} irrespective of soil depth was recorded under application 6 t ha^{-1} sorghum stover. However, irrespective of the treatments, surface layer (0-5 cm) showed higher Alk-P activity of 209.9 µg PNP g^{-1} hr^{-1} compared to sub-surface (165.2 µg PNP g^{-1} hr^{-1}) (Fig 151).

Table 171: Effect of crop residue application on phosphatase activity in soils under sorghum crop

Treatments	Acid phosphatases ug PNP g^{-1} hr^{-1}		Alkaline phosphatases ug PNP g^{-1} hr^{-1}	
	0-5 cm	5-20 cm	0-5 cm	5-20 cm
T1- Control	179.83	128.10	84.05	53.36
T2-2 t ha^{-1} of sorghum residue	429.76	348.86	116.59	102.07
T3- 4 t ha^{-1} of sorghum residue	450.20	370.90	238.52	177.44
T4-6 t ha^{-1} of sorghum residue	549.50	458.20	400.27	328.01
CV @ 0.05 level	*41.55*	*45.70*	*15.29*	*38.51*

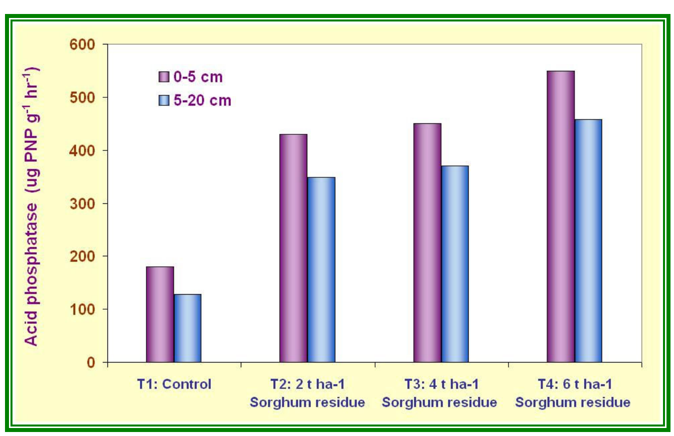

Fig 150: Effect of surface applied crop residue on acid phosphatase activity in soil under minimum tillage

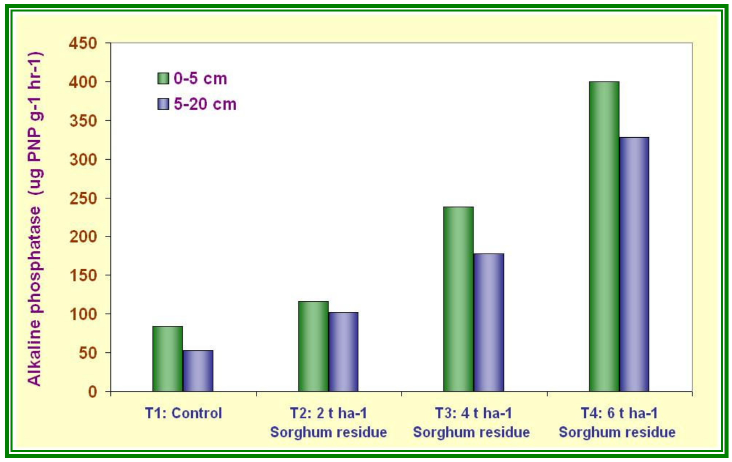

Fig 151: Effect of surface applied crop residue on alkaline phosphatase activity in soil under minimum tillage

4.2.36.4. Study of CO_2 emissions through soil respiration-effect of tillage, residues and N levels

It is well-established fact that CO_2 fluxes from soil and organic matter on soil surface are major components of the terrestrial C cycle. There is no doubt that organic matter content of agricultural soils is highly correlated with their potential productivity, tilth and fertility. Organic matter despite being low in semi-arid dry soils, its effect on soil properties is of major significance even at low concentration. Organic matter is the major substance helping in soil aggregation and structural stability. Stable and good structures helps in improving air and water relationships for root growth and in addition protects the soil from wind and water erosion. The some part of soil organic matter causes the gradual darkening of the soils, which increases their capacity to absorb heat and to warm rapidly during winter (Smith and Elliott, 1990).

Soil organic matter is heterogeneous mixture of living dead, decomposing organic and inorganic compounds. It is derived from plant, animal and microbial tissues and contains various amounts of C, H, O, N, P and traces of other elements. It has been reported that about 15% of SOM constitutes polysaccharides, polypeptides, phenols and other simple organic compounds (Alexander, 1977). The remaining SOM is considered as humic material. This humic material is characterized by dark amorphous colloidal substance derived from chemical, physical and biological transformation of plant and animal material. It is understood that equilibrium level of organic matter depends upon various interacting factors including precipitation, temperature, soil type, tillage, cropping systems, the type and quantity of crop residues returned to the soil and the method of residue application whether surface applied or ploughed in. It has been widely studied that reductions in soil organic matter over time in agricultural soils are largely due to tillage, no or less recycling back to the soil, and soil erosion. When frequent inversion tillage is done and residues are mixed in soil it decomposed fast. Further, tillage breaks down the micro-aggregates and pumps more oxygen in soil, which aggravates the oxidation of entrapped organic matter in soil. The losses in SOM due to tillage in semi- arid regions have been reported to the extent of 20-50 %. Loss of SOM in soil occurs as CO_2 emission. Measurement of soil respiration or CO_2 soil flux when soils are without crop can give some quantitative information on the effect of tillage, residue and fertilizer application and other management factors on SOM loss.

Soil respiration is the total heterotroph metabolism plus a variable component of root respiration, but is a useful indicator of soil activity. Measurement CO_2 flux from soil helps in studying C storage and C budget and build up or depletion in Soil Organic C (SOC) over a period of time The CO_2 emission from soil is mostly influenced by soil temperature, soil moisture microbial activity, tillage, residue application, type of residues, soil moisture and root respiration. If the emissions are measured in soil without crop, then the contribution of root respiration can be minimized.

The CO_2 release pattern from soil as a result of soil respiration has also been studied in this experiment which received sorghum residue @ 0, 2, 4 and 8t ha^{-1} as surface mulch as treatments and 60 Kg N ha^{-1} as uniform dose to sorghum crop in all the plots. The CO_2 flux was recorded after the harvest of the crop during winter months (315 to 30 Julian days). An infrared gas analyzer (IRGA) is considered to be a more appropriate research instrument for measuring CO_2 fluxes. However, in the absence of IRGA, alkali trap method was used to entrap the CO_2 emissions as influenced by tillage and residue treatments. Airtight chambers (59.7 cm x 34.6 cm = 0.206562 Sq m) made up of thick acrylic sheets were installed in the field under different treatments comprising of tillage, residues and N levels. After clipping off the vegetation to the soil surface, the lower end of the chambers were inserted 2-3 cm deep in the soil to ensure better airtight conditions. Soil thermometers were also installed up to 5/10 cm to monitor the soil temperatures simultaneously outside the chamber. The CO_2 measurements were made once in a week staring from November 2005 and data were interpreted as per Julian weeks. A 50 ml of 1 M sodium hydroxide was taken in 100 ml capacity high quality poly propylene jars and these jars were kept hanging above the soil surface in the middle of the acrylic chamber with nylon rope. The jars were removed after 1 hr and lids were tightened. The samples were brought back to the lab each time. To each jar, 1.5 ml saturated Barium Chloride solution was added and unutilized alkali was back titrated with HCl using phenolphthalein as indicator. The end point was pink to colorless.

The reaction goes as follows:

$CO_2 + 2\ NaOH$ ------ Na_2CO_3 (soluble) + H_2O
$Na_2CO_3 + BaCl_2$ ------- $BaCO_3$ (insoluble) + $2NaCl$

Since NaCl (salt) replaces NaOH (alkali), the solution becomes less alkaline. This decrease in alkalinity is proportional to the amount of CO_2 trapped and can be quantified by titration with dilute acid (HCl) to bring the solution to neutral. The sodium hydroxide solution will trap atmospheric CO_2 as a carbonate. This carbonate can then be removed from solution by adding barium chloride to form an insoluble white precipitate of barium carbonate.

The amount of CO_2 emission in mg $m^{-2}\ hr^{-1}$ was computed as follows:

$$= \frac{(\text{Exposed titre} - \text{Blank titre}) \times 0.022}{\text{Exposure time allowed (hrs)} \times 0.206562}$$

Where, 0.206562 is the area of the chamber in sq m.

The CO_2 emissions were measured in this experiment, which received sorghum residue @ 0, 2, 4 and 8t ha^{-1} as surface mulch as treatments and 60 Kg N ha^{-1} as uniform dose to sorghum crop in all the plots. In this experiment, the seeding was done with tractor drawn 5-row seed planter without disturbing the soil (zero tillage). The crop was harvested at the height of 35 cm from surface to allow the stubbles to remain intact on the soil throughout the year after the harvest. While measuring the CO_2 flux, precaution was taken to remove the stubbles and make the surface free from any vegetation so that effect of root respiration could be minimized in soil respiration. As expected, different level of residues significantly influenced the CO_2 emission. The emission rates increased with the amount of residue applied up to 4 t ha^{-1} on most of the Julian dates (between 315^{th} to 30^{th} Julian day). However, on some Julian days, increased CO_2 flux was recoded even under residue applied @ 8 t ha^{-1} (Table 172). On long-term basis, these studies will be of immense use in computation of C balance, sink and stocks in soil and to develop management strategies for enhancing the level of SOC in these soils, which are mostly at the verge of degradation. The methods of measurements of CO_2 flux need to be improved using automatic CO_2 Flux Meters using IRGA (infrared gas analyzers) technique. These studies will be further continued.

Table 172: Effect of residue (sorghum stover) on CO_2 emission in rainfed Alfisols during winter months

Residue	CO₂ emission at different intervals (mg CO_2 sqm^{-1} hr^{-1})								
	Julian Day or day of the year calendar								
	Residue levels	315	339	346	353	360	4	17	30
Sorghum Stover	T1-Control	269	153	218.	148	140	128	73	261
	T2-2t ha	333	240	321.	282	178	165	119	358
	T3- 4t/ha	339	263	380	380	203	181	134	424
	T4-8t/ha	430	289	320	323	209	188	162	380
LSD (P=0.05)			7.0	15.6	14.0	7.69	17.9	3.7	13

4.2.37. Objective 4: To study the influence of tillage, conjunctive use of residues and graded levels of N on castor yield and predominant N pools under sorghum-castor system

With an objective of identifying suitable soil and nutrient management options for sorghum (*Sorghum vulgare* (L)) - castor (*Ricinus communis* (L)) system and to improve soil quality for dryland Alfisols, a field experiment was initiated at Hayathnagar Research Farm (17°18′ N latitude, 78°36′ E longitude and an elevation of 515 m above mean sea level) of Central Research Institute for Dryland Agriculture, Hyderabad, India. The experiment was laid out in a strip split-split plot design with three replications and was maintained since 1995 with sorghum and castor in a two-year rotation. The strip constituted two tillage treatments: minimum tillage (MT) (weeding occasionally with blade harrow or chemical spray and only plough planting) and conventional tillage (CT) (two ploughings before planting + one plough planting + harrowing + operation for top dressing). In the CT strip, ploughing was done with a bullock-drawn country plough to a depth of 10-12 cm at the onset of monsoon during the first week of June. At the time of sowing, the same country plough was used to open a furrow of 5-7 cm depth and seeds were placed by hand in the furrow (also called plough planting). The main plot treatments constituted three residue treatments: dry sorghum stover (SS) (N content of 5 g kg^{-1} and C: N ratio of 72) applied at 2 t ha^{-1}, fresh gliricidia loppings (*Gliricidia maculata*) (GL) (N content of 27.6 g kg^{-1} and C: N ratio of 15) applied at 2 t ha^{-1} (fresh weight) and no residue (NR). Sub plot (4.5 x 6 m^2) treatments consisted of four N rates 0 (N_0), 30 (N_{30}), 60 (N_{60}) and 90 (N_{90}) kg N ha^{-1}. Residues were applied at the surface two weeks after sowing and allowed to decompose in the same plot. Residues acted as a mulch as well as source of organic matter. Nitrogen was applied in two equal splits, one at sowing and another 45 days after sowing. In totality, 24 treatment combinations were evaluated. Phosphorus was applied to each crop at 13 kg P ha^{-1} upto 2005. After the sixth and seventh year of the study, soil quality indices were computed using a rigorous data set of indicators and results were published (Sharma et al., 2005).

4.2.37.1. Sorghum grain yields

Since the initiation of the experiment (1995), sorghum and castor were grown in rotation. During the period from 1995 to 2008, sorghum crop was grown during the years 1995, 1997, 1999, 2001, 2003, 2005, and 2007. In the year 2003, crop failed due to severe drought spell. The data on the average long-term influence of tillage, residues and N levels on sorghum grain yields is presented in Tables 173 to 174 & Fig 152 to 154. Statistical analysis of the data revealed a significant influence of years, tillage, residues as well as the N levels on sorghum grain yields. Of all the years, on an average over tillage, residues and N levels, sorghum grain yields were highest (1521 kg ha^{-1}) during the year 2007 followed by the yields (1252 kg ha^{-1}) during 1999 while the yields were very low (742 kg ha^{-1}) during 1997. Of the tillages, on an average, conventional tillage out performed over the minimum tillage in recording the sorghum grain yields during all the years. The average sorghum grain yields under conventional tillage were 1248 kg ha^{-1} while under minimum tillage it was 957 kg ha^{-1} amounting to 30.4% increase over the minimum tillage. Among the residues applied, gliricidia application outperformed the other two residue treatments and recorded sorghum grain yields to the extent of 1156 kg ha^{-1}, followed by sorghum stover application (1094 kg ha^{-1}) and no residue application (1058 kg ha^{-1}). Average sorghum grain yields showed a tremendous response towards the application of N levels and it was observed that the yields increased with increase in N level gradient. The average sorghum grain yields with the respective N levels were: 1425 kg ha^{-1} with 90 kg ha^{-1}, 1292 kg ha^{-1} with 60 kg N ha^{-1}, 1067 kg ha^{-1} at 30 kg N level while at 0 level, the yields were only to the extent of 626 kg ha^{-1}. The increase in sorghum grain yields over the 0 level was to the extent of 70.4%, 106.4 % and 127.6 % at 30, 60 and 90 kg levels respectively.

Table 173: Effect of tillage, residues and N levels on sorghum grain yield under sorghum-castor system

Sno	Tillage	Residues	N levels	1995	1997	1999	2001	2005	2007	Pooled analysis
1	Conventional tillage	Sorghum stover	N0	468	603	721	704	520	990	668
			N30	837	832	1541	997	1170	1733	1185
			N60	1048	1390	1739	1241	1492	1918	1471
			N90	1174	1426	1839	1467	1734	2463	1684
		Gliricidia loppings	N0	484	716	767	690	602	979	706
			N30	928	824	1570	1041	1352	1857	1262
			N60	1452	1220	1788	1376	1548	1957	1557
			N90	1265	1424	1836	1832	1822	2024	1700
		No residue	N0	710	725	758	582	489	898	693
			N30	1000	805	1497	848	1109	1654	1152
			N60	1258	942	1743	1155	1360	1748	1368
			N90	1190	1236	1803	1405	1793	1760	1531
2	Minimum tillage	Sorghum stover	N0	559	393	581	533	272	967	551
			N30	754	432	1126	872	891	1389	911
			N60	936	500	1227	1038	1279	1554	1089
			N90	1146	622	1187	1058	1462	1662	1189
		Gliricidia loppings	N0	686	413	444	618	286	926	562
			N30	1000	427	1142	975	1002	1366	985
			N60	1349	457	1168	1175	1363	1635	1191
			N90	1376	462	1420	1217	1547	1699	1287

Sno	Tillage	Residues	N levels	1995	1997	1999	2001	2005	2007	Pooled analysis
		No residue	N0	615	375	648	662	245	917	577
			N30	857	453	1126	869	793	1345	907
			N60	1119	530	1148	996	1178	1498	1078
			N90	1214	590	1237	1000	1346	1554	1157
	Tillage		-	-	-	-	-	-	-	-
	Residue		-	-	-	-	-	-	-	-
	Nitrogen		-	-	-	-	-	-	-	-
	T X R		-	-	-	-	-	-	-	-
	T X N		-	-	-	-	-	-	-	-
	R X N		-	-	-	-	-	-	-	-
	T X R X N		-	-	-	-	-	-	-	-

* and ** Indicates significant difference at $P = 0.05$ and $P = 0.01$, respectively; NS: non significant at $P > 0.05$.

Table 174: Long-term effect of tillage, residues and N levels on sorghum grain yields under 13-year sorghum-castor rotation system (Alternately sorghum was grown for 6 years and castor for 7 years)

Sno	Treatments	Sorghum grain yields (kg ha^{-1})						
		1995	1997	1999	2001	2005	2007	Mean
1	**Tillage**							
	Conventional tillage	985	1012	1467	1111	1249	1665	1248
	Minimum tillage	968	471	1038	918	972	1376	957
	Residues							
	Sorghum stover	865	775	1245	989	1103	1585	1094
	Gliricidia loppings	1068	743	1267	1115	1190	1556	1156
	No residue	995	707	1245	939	1039	1421	1058
	N levels							
	N0	587	537	653	631	402	946	626
	N30	896	629	1334	934	1053	1557	1067
	N60	1194	840	1469	1163	1370	1718	1292
	N90	1228	960	1554	1330	1617	1860	1425
	CD @ 0.05							
	Years				**			
	Tillage				**			
	Residues				**			
	N levels				**			
	Years x T				**			
	Years x R				**			
	Years x N				**			
	T x R				*			
	T x N				**			
	R x N				**			
	Years x R				NS			
	Years x T x R				**			
	T x R x N				NS			
	Years x R x N				**			
	Years x T x R x N				**			

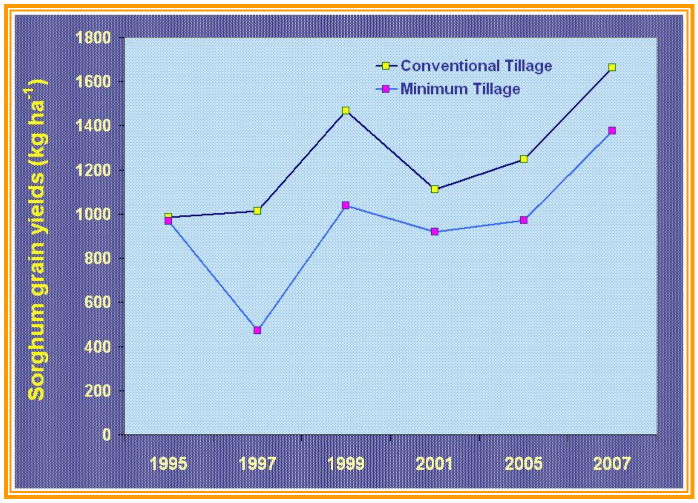

Fig 152: Sorghum grain yields as influenced by conventional and minimum tillage over seven years in rainfed Alfisols of Hyderabad

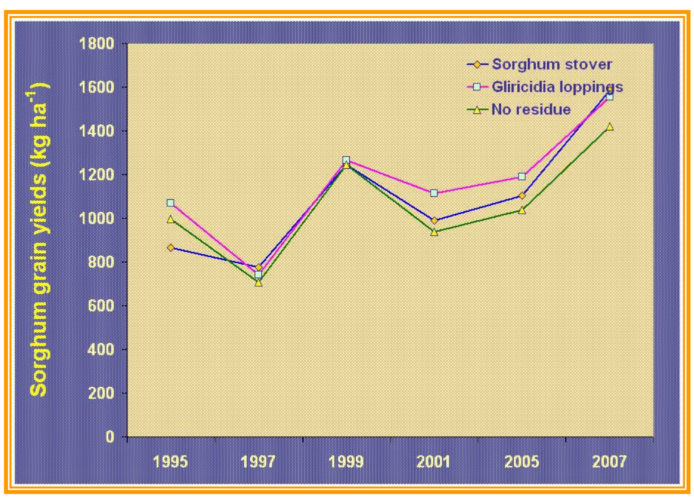

Fig 153: Sorghum grain yields as influenced by different residues over seven years in rainfed Alfisols of Hyderabad

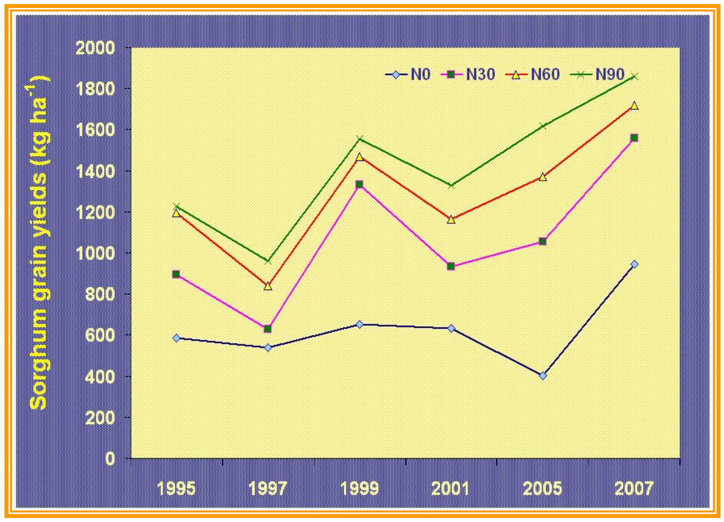

Fig 154: Sorghum grain yields as influenced by different N levels over seven years in rainfed Alfisols of Hyderabad

4.2.37.2. Castor crop yields

During the period from 1995 to 2008, castor crop was grown only during the years 1996, 1998, 2000, 2002, 2004, 2006 and 2008. The data on the long-term influence of tillage, residues and N levels on castor pod yields is presented in Tables 175 to 176 & Fig 155 to 157. Statistical analysis of the data revealed a significant influence of years, tillage, residues as well as the N levels on castor pod yields. Of all the years, when averaged over tillage, residues and N levels, castor pod yields were highest (930 kg ha^{-1}) during the year 2000 followed by the yields (742 kg ha^{-1}) during 2004 while the yields were very low (470 kg ha^{-1}) during 1998. Of the tillages, on an average, conventional tillage out performed over the minimum tillage in recording the castor bean yields during all the years. The average castor bean yields under conventional tillage were 826 kg ha^{-1} while under minimum tillage it was 526 kg ha^{-1} amounting to 57.0 % increase over the minimum tillage. Among the residues applied, gliricidia application outperformed the other two residue treatments and recorded castor bean yields to the extent of 726 kg ha^{-1}, followed by sorghum stover application (666 kg ha^{-1}) and no residue application (638 kg ha^{-1}). Average castor bean yields showed a tremendous response towards the application of N levels and it was observed that the yields increased with increase in N level gradient. The average castor bean yields with the respective N levels were: 876 kg ha^{-1} with 90 kg ha^{-1}, 749 kg ha^{-1} with 60 kg N ha^{-1}, 639 kg ha^{-1} at 30 kg N level while at 0 level, the yields were only to the extent of 441 kg ha^{-1}. The increase in castor bean yields over the 0 level was to the extent of 44.9 %, 69.8 % and 98.6 % at 30, 60 and 90 kg levels respectively.

On an average, conventional tillage maintained higher grain yields of sorghum and castor to the tune of 30.4% and 57.0% respectively over minimum tillage. Among the residues, gliricidia application out performed the other two residues treatments in case of both the crops. Response of both the crops to graded levels of N application was tremendous. The highest yields of sorghum (1425 kg ha^{-1}) and castor (876 kg ha^{-1}) were recorded with application of 90 kg N ha^{-1}.

Table 175: Effect of tillage, residues and N levels on castor (DCS 9) bean yield under sorghum-castor system

Sno	Tillage	Residues	N levels	1996	1998	2000	2002	2004	2006	2008	Pooled analysis
1	Conventional tillage	Sorghum stover	N0	496	414	667	540	646	526	419	530
			N30	742	535	1223	765	842	707	725	791
			N60	938	691	1196	843	923	812	828	890
			N90	998	877	1238	967	1022	993	1001	1014
		Gliricidia loppings	N0	576	505	832	575	625	598	404	588
			N30	857	793	1218	927	846	796	749	884
			N60	988	975	1263	931	1085	845	849	991
			N90	1002	1013	1355	989	1176	1032	1018	1083
		No residue	N0	553	491	640	505	598	496	368	522
			N30	696	624	1222	687	613	658	685	741
			N60	1073	824	1190	798	893	716	720	888
			N90	1043	895	1306	904	1011	941	872	996
2	Minimum tillage	Sorghum stover	N0	48	65	534	432	497	376	394	335
			N30	189	192	682	574	559	423	546	452
			N60	525	225	814	678	652	500	769	595
			N90	636	397	842	807	835	611	891	717
		Gliricidia loppings	N0	73	85	497	468	507	404	385	346
			N30	264	184	705	710	695	588	584	533
			N60	524	234	789	724	621	644	775	616
			N90	715	409	949	788	830	759	904	765
		No residue	N0	48	68	586	395	448	331	392	324
			N30	154	188	817	423	529	473	464	435
			N60	268	223	833	573	576	534	611	517
			N90	600	383	911	693	787	589	790	679
	Tillage		-	-	-	-	-	-	-	-	-
	Residue		-	-	-	-	-	-	-	-	-
	Nitrogen		-	-	-	-	-	-	-	-	-
	T X R		-	-	-	-	-	-	-	-	-
	T X N		-	-	-	-	-	-	-	-	-
	R X N		-	-	-	-	-	-	-	-	-
	T X R X N		-	-	-	-	-	-	-	-	-

* and ** Indicates significant difference at $P = 0.05$ and $P = 0.01$, respectively; NS: non significant at $P > 0.05$.

Table 176: Long-term effect of tillage, residues and N levels on castor bean yields under 13-year sorghum-castor rotation system (Alternately sorghum was grown for 6 years and castor for 7 years)

Sno	Treatments	Castor pod yields (kg ha^{-1})							
		1996	1998	2000	2002	2004	2006	2008	Pooled analysis
1	**Tillage**								
	Conventional tillage	830	720	1113	786	857	760	720	826
	Minimum tillage	337	221	747	605	628	519	626	526
	Residues								
	Sorghum stover	572	424	899	701	747	619	697	666
	Gliricidia loppings	625	525	951	764	798	708	709	726
	No residue	555	462	938	623	682	592	613	638
	N levels								
	N0	299	271	626	486	554	455	394	441
	N30	484	419	978	681	681	608	625	639
	N60	719	529	1014	758	791	675	759	749
	N90	832	662	1100	858	943	821	913	876
	CD @ 0.05								
	Years					**			
	Tillage					**			
	Residues					**			
	N levels					**			
	Years x T					**			
	Years x R					**			
	Years x N					**			
	T x R					*			
	T x N					**			
	R x N					NS			
	Years x R					NS			
	Years x T x R					**			
	T x R x N					NS			
	Years x R x N					NS			
	Years x T x R x N					**			

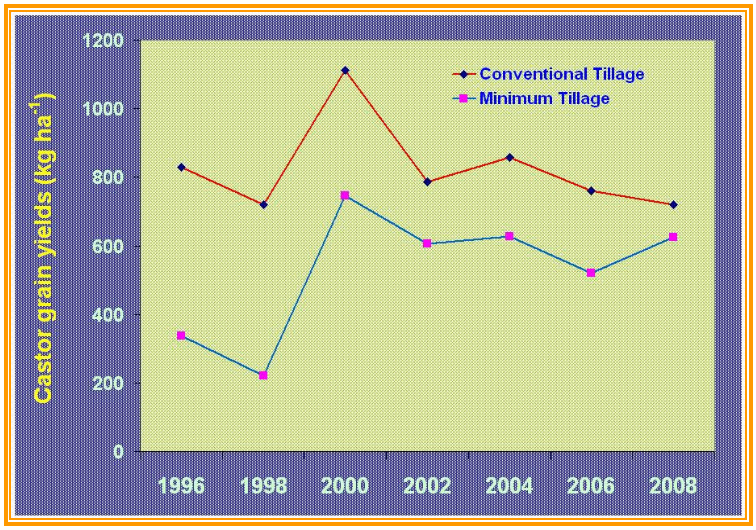

Fig 155: Castor bean yields as influenced by conventional and minimum tillage over seven years in rainfed Alfisols of Hyderabad

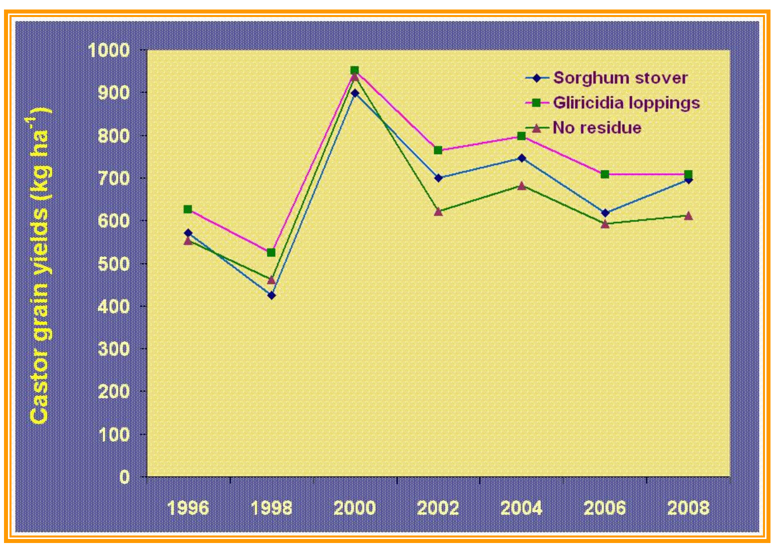

Fig 156: Castor bean yields as influenced by different residues over seven years in rainfed Alfisols of Hyderabad

Fig 157: Castor bean yields as influenced by different N levels over seven years in rainfed Alfisols of Hyderabad

4.2.37.3. Study of CO_2 emissions through soil respiration - effect of tillage, residues and N levels in castor –sorghum system

The studies were undertaken in this eleven year old (during 2005) experiment with sorghum-castor as crop rotation. Sorghum crop was sown under minimum tillage conditions using five-row tractor drawn planter/ non inversion type plough. . Apart from recording the yield, CO_2 flux was also recorded after the harvest of the crop during winter months (315 to 30 Julian days).

The data on CO_2 emissions as influenced by tillage, residue application and nitrogen levels are presented in Table 177 & Fig 158. CO_2 emission was significantly influenced by residues and N levels. However, significant effect of tillage was not seen on some of the Julian days. Irrespective of N levels and residues, in minimum tillage plots, relatively higher CO_2 emission (232.0 mg CO_2 m^{-2} hr^{-1}) was recorded compared to conventional tillage (216.0 mg CO_2 m^{-2} hr^{-1}). This may be attributed to higher microbial activity because of more biomass availability for microbial respiration. Moreover, the observations were recorded after 5 months of the tillage treatments (or sowing of crop) i.e. immediately after harvest of the crop. Presumably, by that time, the oxidative influence of conventional tillage might have come down because of compaction, etc. On an average, the plots which received nitrogen @ 60 Kg N ha^{-1} (236.5 mg CO_2 m^{-2} hr^{-1}) showed significantly higher CO_2 emissions compared to control (210.5 mg CO_2 m^{-2} hr^{-1}). On an average over tillage and N levels, among the residues, highest amount of emission was recorded in the plots which received sorghum stover (232.5 mg CO_2 m^{-2} hr^{-1}) followed by gliricidia (225.0 mg CO_2 m^{-2} hr^{-1}). The plots that did not receive any residue showed significantly lower emissions (213.5 mg CO_2 m^{-2} hr^{-1}). Prima facie, from the data, it was seen that the extent of emission of CO_2 under these semi-arid tropical Alfisols during winter months (Nov.-Jan) having soil temperature 26.2 to 32.3 °C, varied from as low as 150 mg CO_2 m^{-2} hr^{-1} to as high as 323 mg CO_2 m^{-2} hr^{-1}.

Table 177: Effect of tillage, residues and N levels on CO_2 emission in rainfed Alfisols during winter months in sorghum castor system

Tillage	Residues	CO_2 emission at different intervals (mg CO_2 sqm^{-1} hr^{-1})									
		Julian Day or day of the year calendar									
		N levels	315	332	339	346	353	360	4	17	30
CT	Sorghum stover	N0	323	206	150	233	237	230	191	192	162
		N60	367	244	181	289	261	258	240	210	208
	Gliricidia	N0	207	238	131	213	224	228	120	166	232
		N60	255	253	152	237	238	243	186	189	255
	No residue	N0	201	233	153	185	211	202	197	174	222
		N60	232	239	165	194	221	218	207	190	247
MT	Sorghum stover	N0	206	219	201	238	262	254	223	199	191
		N60	244	262	226	254	283	269	225	224	222
	Gliricidia	N0	232	237	226	208	242	235	152	233	244
		N60	283	261	250	223	264	249	253	245	294
	No residue	N0	283	235	194	189	220	222	158	178	236
		N60	269	248	207	213	235	235	219	193	255
	Tillage (T)		NS	NS	**	NS	**	**	**	*	**
	Residue (R)		**	**	*	**	**	**	**	**	**
	Nitrogen (N)		**	**	**	**	**	**	**	**	**
	T x R		**	NS	**	**	**	*	**	**	**
	T x N		*	**	NS	*	NS	NS	**	NS	NS
	R x N		**	**	NS	**	*	NS	**	NS	**
	T x R x N		*	NS	NS	**	NS	NS	**	*	**

CT: Conventional tillage; MT: Minimum tillage; NS: Non-significant
*Significant difference at p=0.05.
** Significant difference at p=0.01

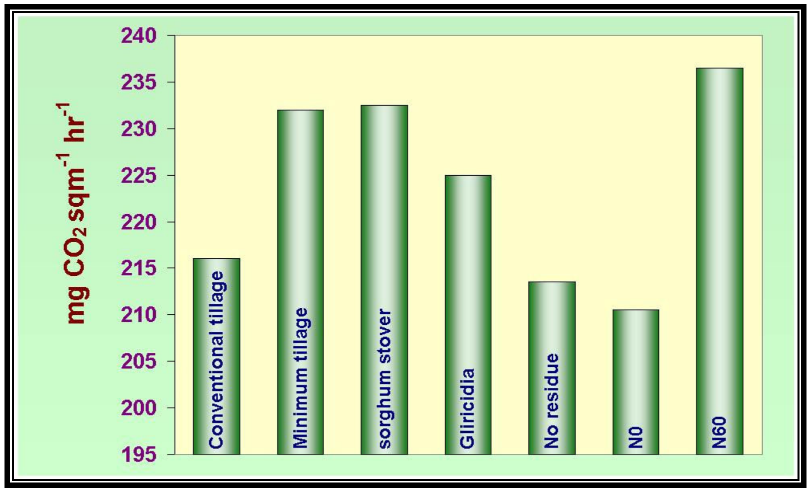

Fig 158: Effect of tillage, residues and N levels on CO_2 emission in rainfed Alfisol during winter months (315 to 30 Julian days) –Average effects

4.2.37.4. Effect of tillage, conjunctive use of residues and graded levels of N on predominant N fractions (N chemical pools) under sorghum-castor system

In order to study the effect of management practices (tillages, crop residues, graded levels of N and cropping systems) on different fractions/ pools of nitrogen and their transformation from one pool to another, nitrogen fractionation study was undertaken in sorghum -castor system after 13th year of experimentation. The detailed methodology and the results are presented in the following section.

4.2.37.4.1. Methodology followed for estimation of nitrogen fractions

The methodology adopted for estimation of various N fractions is as follows: In order to determine the inorganic N fractions, as a preliminary step, 2 N KCl extract (1:5) of the soil was prepared and i) exchangeable ammonical N was determined by distilling a part of the extract with light MgO in Kjeldahl flask; ii) to determine the nitrate-N fraction, 50 ml of the above extract when distilled with MgO and Devardas alloy gave both ammonical and nitrate N fractions from which nitrate N was estimated by difference.

In order to determine the organic N fractions, the soil residue obtained after leaching with 2N KCl (pH 1.0) was transferred to 500 ml Erlenmeyer flask to which 6N HCl was added (soil: HCl ratio

1:4). The suspension was digested for 12 hours in a water bath at constant temperature of 100^oC (under reflux) with two drops of octyl alcohol. The hydrolyzate mixture was filtered under suction with repeated washing with distilled water. The pH of the extract was adjusted to 6.5± 0.1 with dilute NaOH and contents were made to volume with distilled water. The residue left on the filter paper was saved for estimation of fixed ammonium in soil. To determine total hydrolysable N, 10 ml of the above-neutralized extract was digested with 1 gm of K_2SO_4 catalyst mixture and 10 ml of concentrated H_2SO_4 in a 100 ml Kjeldahl flask. The digest so obtained was distilled under alkaline conditions into 2% boric acid and finally titrated with 0.005 N H_2SO_4 (Bremner, 1965). The components of total hydrolyzable nitrogen viz., hydrolyzable ammonical N, hexosamine N, amino acid N and the unidentified N were also estimated. i) First, to obtain the fraction of hydrolyzable ammonical N, 25 ml of neutralized extract was distilled with 0.2 gm of light MgO; ii) Secondly, in order to determine the hexosamine N, 25 ml of the above neutralized extract was taken in a distillation flask and 25 ml of phosphate –borate buffer (pH 11.2) was added and distilled after adding MgO. This gives both hexosamine and hydrolyzable ammonical N from which the hexosamine N fraction was estimated by difference between the values obtained from the previous fraction; iii) Thirdly, to determine the amino acid N fraction, to the 5 ml of the hydrolyzate in 50 ml of Erlenmeyer flask, one ml of 0.5 N NaOH was added and the contents were heated in boiling water. On cooling, 500 mg of citric acid and 100 mg of ninhydrin were added to the flask and kept immersed in boiling water for about 10 min. The contents were transferred quantitatively to a Kjeldahl distillation flask. 10 ml of phosphate-borate buffer and one ml of 5 N NaOH were added and distillation was carried out to estimate the amino acid N fraction; iv) Fourthly, the unidentified hydrolysable N fraction was determined by subtracting the sum of hydrolysable ammonical N, hexosamine N and amino acid N from the total hydrolysable N. Finally, to determine the fixed ammonical N, the residue which was left on the filter paper after acid hydrolysis was transferred to 500 ml polythene Erlenmeyer flask. To this, 100 ml mixture of 5 N HF-1N HCl was added (soil mixture ration 1:5, ie 20: 100), mixed well and allowed to remain covered for 24 hours at room temperature. The suspension was filtered and the entire leachate was distilled with 125 ml of 10 N NaOH to obtain the fixed ammonical N fraction (Cheng and Kurtz, 1963). The data thus obtained on different N fractions was statistically analyzed using the same design (Split plot design) in which this field experiment was conducted and the results are discussed hereunder.

4.2.37.4.2. Results

The data on the long-term influence of tillage, residues and N levels on various inorganic and organic N factions studied under various treatments in sorghum-castor rotation is presented in Tables 178 to 179 & Fig 169 to 164. Among the inorganic fractions, exchangeable ammonical nitrogen fraction varied from 17.1 to 42.1 mg kg^{-1} while the nitrate-N varied between 3.89 to 13.4

mg kg^{-1} across the management treatments. Significantly highest ammonical N was observed under conventional tillage (35.5 mg kg^{-1}) than under minimum tillage (26.8 mg kg^{-1}), but the nitrate N was not significantly influenced by tillage. Application of residues viz., sorghum stover and gliricidia loppings performed equally well in maintaining significantly highest inorganic N fractions when compared to ‘no residue’ application. Interestingly, both ammonical and nitrate N fractions significantly improved with increase in N levels applied to the soil. However, the interaction effects of tillage, residues and N levels did not influence the contents of ammonical and nitrate N fractions in these soils. The organic N fractions were estimated as the total hydrolyzable N which constituted hydrolyzable ammonical N, hexosamine N, amino acid N, and unidentified N. Total hydrolyzable N fraction varied from 333.6 to 648.9 mg kg^{-1} of soil across the management treatments and was not significantly influenced by the tillage practices. Among the residues, on an average, significantly highest total hydrolyzable N was observed under application of sorghum residues (508.5 mg kg^{-1}) followed by gliricidia loppings (481.6 mg kg^{-1}) while ‘no residue’ plots maintained total hydrolyzable N to the extent of 440.4 mg kg^{-1}. Again, it was interesting to note that, significant increase in total hydrolyzable N was observed with increase in N levels, with the highest value recorded in plots receiving N @ 90 kg N ha^{-1} (577.2 mg kg^{-1}). The interaction effects on total hydrolyzable N content were not quite conspicuous except the tillage x residue interaction. The data on various constituent fractions of total hydrolyzable N as mentioned above viz., hydrolyzable ammonical N, hexosamine N, Amino acid N, and unidentified N is discussed as follows: On an average, hydrolyzable ammonical N constituted 13.01% to the total hydrolyzable N (Fig 163) and varied from 41.2 to 83.6 mg kg^{-1} across the management treatments. The trend of the significant influence of the management treatments on hydrolyzable ammonical N was similar to the total hydrolyzable N fractions. Tillage had no conspicuous influence on hydrolyzable ammonical N, while among the residues, sorghum stover application recorded significantly highest hydrolyzable ammonical N content of 66.1 mg kg^{-1} followed by gliricidia loppings (63.9 mg kg^{-1}). Finally hydrolyzable ammonical N content increased with increase in N levels and the interaction effects were not so conspicuous.

Table 178: Long-term effect of tillage, residues and N levels on nitrogen fractions (in mg kg^{-1}) under 13 year sorghum-castor rotation system

Sno	Tillage	Residues	N levels	Exch. NH_4-N	Nitrate- N	Total Hydrolyzable N	Hydrolyzable NH_4-N
1	Conventional tillage	Sorghum stover	N0	22.2	6.55	367.8	49.4
			N30	34.1	9.68	434.0	60.2
			N60	38.3	11.6	576.1	69.4
			N90	40.4	12.7	597.3	73.1
		Gliricidia loppings	N0	20.1	7.16	382.9	49.5
			N30	32.1	10.0	470.4	59.8
			N60	39.2	12.9	526.1	63.9
			N90	42.1	13.4	605.0	70.6
		No residue	N0	19.9	4.61	337.8	42.6
			N30	31.8	4.31	416.3	54.6
			N60	33.8	5.66	457.2	60.6
			N90	35.9	7.75	504.0	68.6
2	Minimum tillage	Sorghum stover	N0	18.8	7.97	375.8	47.7
			N30	27.8	9.47	512.4	67.8
			N60	34.1	11.5	555.8	78.0
			N90	36.4	12.4	648.9	83.6
		Gliricidia loppings	N0	19.1	7.78	377.9	51.5
			N30	24.3	9.96	436.7	65.0
			N60	29.3	11.6	505.6	72.8
			N90	33.3	12.7	548.4	78.4
		No residue	N0	17.1	4.12	333.6	41.2
			N30	23.8	3.89	426.0	48.5
			N60	26.2	5.07	489.2	66.9
			N90	31.8	6.96	559.4	64.7
	Tillage			*	NS	NS	NS
	Residue			*	**	**	**
	Nitrogen			**	**	**	**
	T X R			NS	NS	**	**
	T X N			*	NS	NS	NS
	R X N			NS	NS	NS	NS
	T X R X N			NS	NS	NS	NS

Hexosamine N fraction contributed only 8.41 % towards total hydrolyzable N fraction and varied from 20.9 to 59.3 mg kg^{-1} across the various management treatments. Conspicuous influence of the application of residues and N levels on hexosamine N was observed while the influence of tillage and other interaction effects was not noticed. Even among the residue treatments, application of both sorghum stover as well as gliricidia loppings performed equally in influencing the hexosamine N fraction in soil and maintained significantly highest hexosamine N content of

43.1 mg kg^{-1} and 42.4 mg kg^{-1} respectively while the 'no residue' application recorded only 34.7 mg kg^{-1} of hexosamine N content. This fraction increased with increase in N levels and was highest with N applied @ 90 kg ha^{-1} (54.4 mg kg^{-1} of soil). None of the interaction effects were significant in influencing the hexosamine content. Amino acid N made the highest contribution of 51.5% towards total hydrolyzable N and varied from 178.8 to 308.0 mg kg^{-1} across the management treatments. Tillage, residues as well as N levels significantly influenced the amino acid N fraction. On an average, significantly highest amino acid N content was observed under minimum tillage (265.0 mg kg^{-1}) followed by conventional tillage (225.7 mg kg^{-1}). Among the residues, application of sorghum stover and gliricidia residues performed equally well in maintaining amino acid N content to the extent of 255.5 mg kg^{-1} and 258.3 mg kg^{-1} respectively while the corresponding content in 'no residue' plots was to the tune of 222.2 mg kg^{-1}. Application of 90 kg N ha^{-1} recorded significantly highest amino acid N to the extent of 272.4 mg kg^{-1}. The quantum of unidentified N was to the extent of 21.4 % to the total hydrolyzable N in the soil and varied between 73.2 to 215.5 mg kg^{-1} across the treatments. From the data, it was observed that the unidentified N fraction was significantly highest under conventional tillage (148.7 mg kg^{-1}) while under minimum tillage it was 110.2 mg kg^{-1}. Among the residues, on an average, the unidentified N fractions were significantly lower under application of gliricidia loppings (117.0 mg kg^{-1}) followed by 'no residue' application (127.5 mg kg^{-1}) while it was slightly higher under sorghum stover application (143.7 mg kg^{-1}). Similar to other fractions, the unidentified N fraction also increased with increase in N levels and was highest under application of N @ 90 kg ha^{-1} (177.2 mg kg^{-1}). Fixed ammonical N, which represent the nitrogen retained in the clay lattices, varied between 97.8 to 183.8 mg kg^{-1} across the management treatments and was significantly influenced by tillage, residue application as well as varying N levels. Fixed ammonical N was significantly highest under minimum tillage (153.6 mg kg^{-1}) compared to conventional tillage (125.0 mg kg^{-1}). Among the residue treatments, this fraction was observed to be highest under gliricidia loppings application (146.6 mg kg^{-1}), which was at par with sorghum stover application (141.8 mg kg^{-1}) while the plots, which received 'no residue', recorded fixed ammonical N content of 129.5 mg kg^{-1}. Nitrogen levels applied @ 60 and 90 kg ha^{-1} recorded fixed ammonical N to the extent of 150.7 and 159.0 mg kg^{-1} respectively while N applied at 30 kg ha^{-1} recorded 141.8 mg kg^{-1}. Interaction effects of tillage, residues and N levels did not show much influence on fixed ammonical N. In order to ascertain the quantitative contribution of these predominant pools towards plant N uptake and nitrogen availability indices (available N) and to find out the pathway of transformation, more rigorous statistically analysis such as multiple regression and path analysis has to be carried out in future.

Table 179: Long-term effect of tillage, residues and N levels on nitrogen fractions (in mg kg^{-1}) after 13 years of experimentation under sorghum-castor rotation

Sno	Tillage	Residues	N levels	Hexosamine N	Amino acid N	Unidentified N	Fixed Ammonical N
1	Conventional tillage	Sorghum stover	N0	26.7	212.6	79.1	105.1
			N30	36.6	228.3	108.9	123.0
			N60	47.4	259.9	199.4	135.8
			N90	53.4	273.2	197.6	145.4
		Gliricidia loppings	N0	26.6	221.5	85.3	109.7
			N30	34.5	231.9	144.2	128.8
			N60	45.0	242.3	175.0	137.8
			N90	57.5	262.6	214.2	144.9
		No residue	N0	20.9	178.8	95.5	97.8
			N30	29.3	189.0	143.3	117.8
			N60	36.5	192.8	167.3	123.5
			N90	45.8	215.4	174.1	129.9
2	Minimum tillage	Sorghum stover	N0	31.3	228.5	68.3	111.4
			N30	39.4	270.0	135.3	162.9
			N60	49.1	282.9	145.8	171.1
			N90	61.3	288.5	215.5	179.6
		Gliricidia loppings	N0	30.8	235.5	60.0	108.6
			N30	38.0	260.6	73.2	177.2
			N60	47.4	303.8	81.6	181.7
			N90	59.3	308.0	102.7	183.8
		No residue	N0	24.7	194.1	73.5	101.5
			N30	36.8	256.2	84.5	141.2
			N60	34.9	264.6	122.7	154.1
			N90	48.8	287.0	158.9	170.4
	Tillage			NS	*	*	**
	Residue			*	**	**	*
	Nitrogen			**	**	**	**
	T X R			NS	NS	**	NS
	T X N			NS	NS	NS	**
	R X N			NS	NS	NS	NS
	T X R X N			NS	NS	*	NS

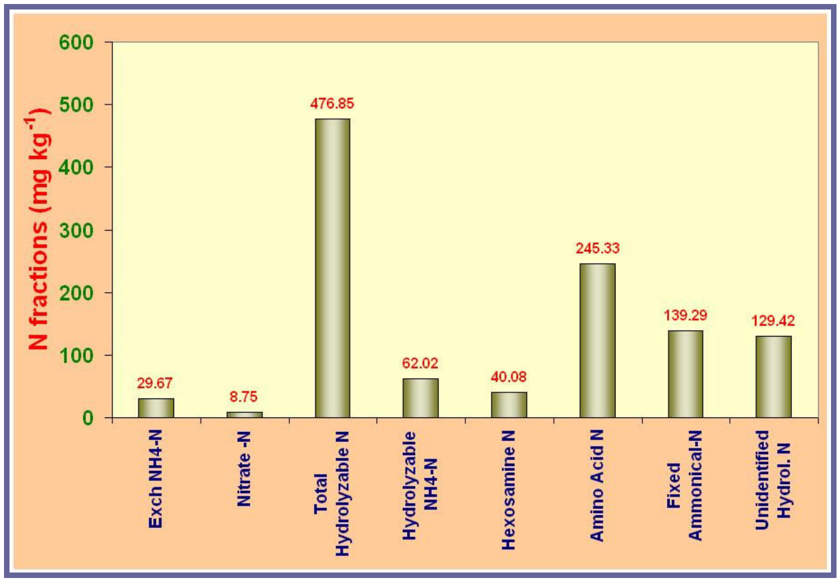

Fig 159: Long-term effect of tillage, residues and N levels on nitrogen fractions (in mg kg^{-1}) after 13 years of experimentation under sorghum-castor rotation

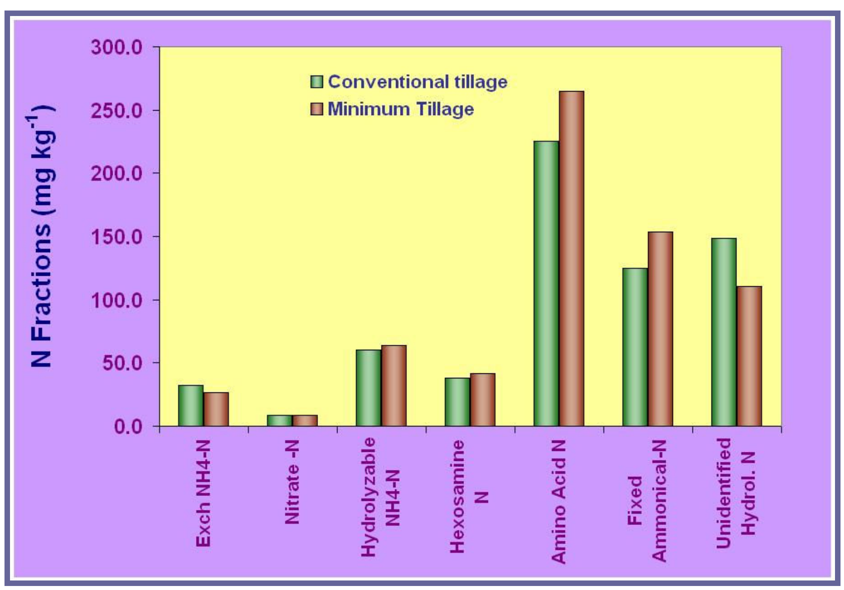

Fig 160: Nitrogen fractions as influenced by conventional and minimum tillage after 13 years of experimentation under sorghum-castor rotation

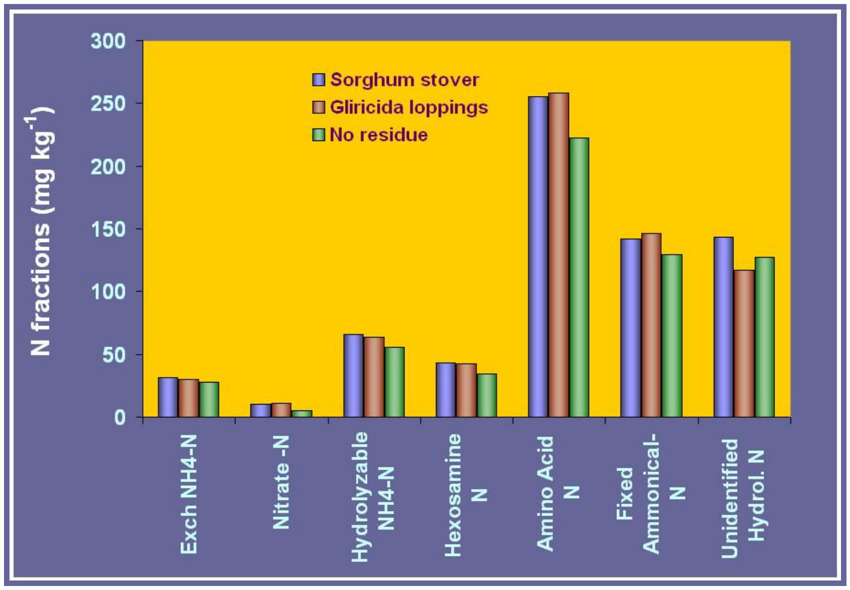

Fig 161: Nitrogen fractions as influenced by different residue treatments after 13 years of experimentation under sorghum-castor rotation

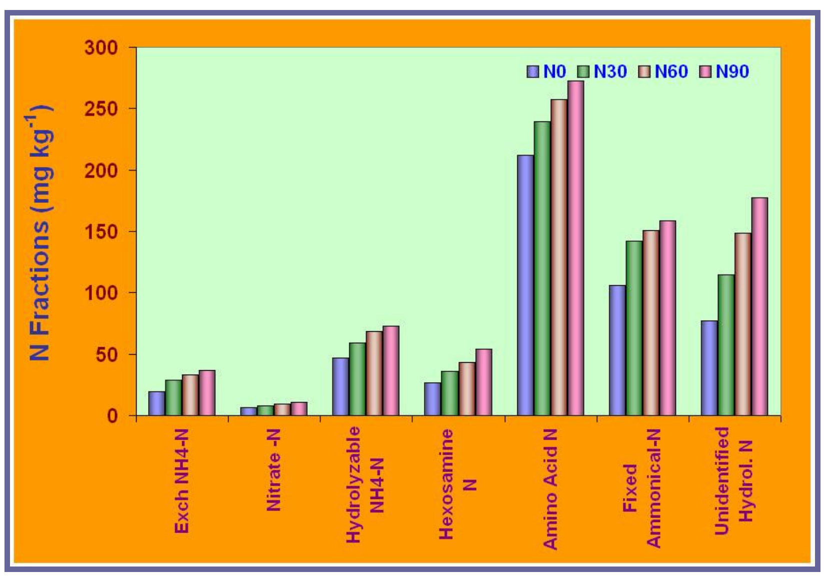

Fig 162: Nitrogen fractions as influenced by different nitrogen levels after 13 years of experimentation under sorghum-castor rotation

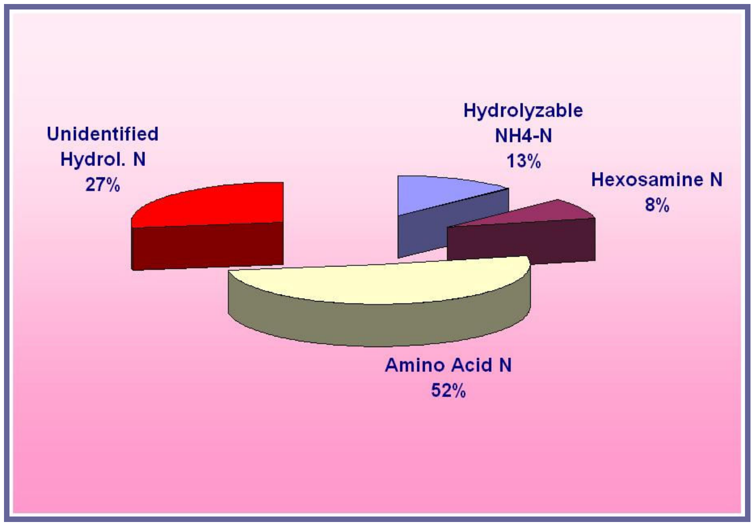

Fig 163: Components of total hydrolyzable nitrogen as influenced by tillage, residues and N levels after 13 years of experimentation under sorghum-castor rotation

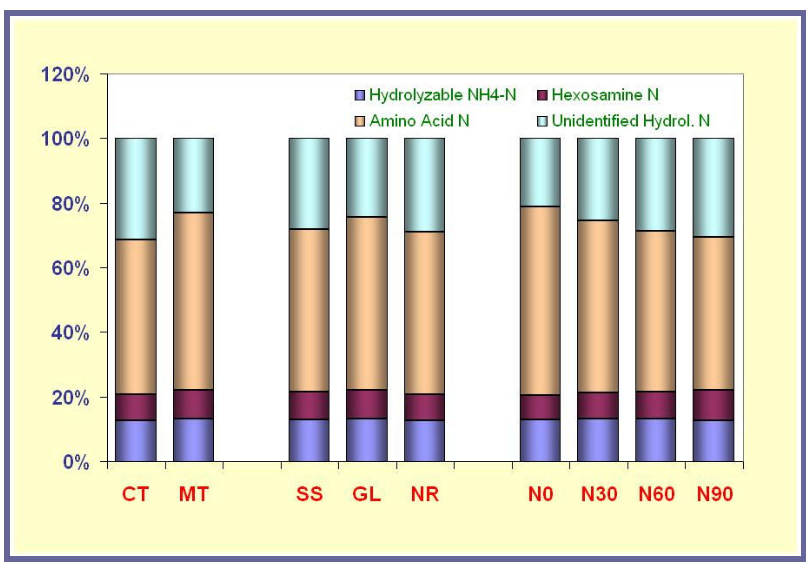

Fig 164: Component fractions of total hydrolyzable nitrogen as influenced by tillage, residues and N levels after 13 years of experimentation under sorghum-castor rotation

4.3. Summary of salient findings and practical utility:

Consequent to the above, mentioned reasons, soils encounter diversity of constrains on account of physical, chemical and biological soil health and ultimately end up with poor functional capacity (soil quality) resulting into low productivity. To reverse some of the above adversaries of soil degradation, there is no other way than to focus on effective land protection and soil quality restoration and improvement measures. Some of the measures such as conservation agriculture practices viz., reduced tillage, surface residue application, green manuring, integrated use of organic and inorganic source of nutrients, non-pesticidal insect management, balanced fertilizer application with special emphasis on limiting nutrients, enhancement of fertilizer doses according to targeted yields and crop removal rates could be effective in protecting the land from further degradation and in improvement and restoration of soil quality. In rainfed agro-ecosystem, various soil-nutrient management practices are being experimented for last many years at experimental stations of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) under different soil types, varying climatic conditions in different cropping systems. Besides these, farmers are also following different level of management at manage their farms. Some of these practices are quite beneficial and aggradative in nature, whereas, others are degradative.

Thus, keeping in view the above and to monitor the aggradative and degradative practices and to identify the key indicators of soil quality to compute Soil Quality Indices for different management practices and situations (soil type, climate, cropping systems etc.) across the country, the present study entitling **"Assessing soil quality key indicators for development of soil quality index using latest approaches under predominant management practices in rainfed agroecology"** was under taken under National Fellowship Program from 2005 to 2010 with the following objectives :

Objective 1: To evaluate the long term influence of existing selected soil and nutrient management practices on soil quality parameters, to identify the key indicators and to compute the soil quality indices under different cropping systems in rainfed areas across the country.

Objective 2: To evaluate the low-cost integrated nutrient management (INM) treatments (comprising of farm based organics) under conventional and reduced tillage in sorghum-mung bean strip cropping system in terms of sustainability of crop yields and long term effects on soil quality in Alfisol

Objective 3: To study the response of sorghum-cowpea system to graded level of surface residue application under minimum tillage in Alfisol and effects on carbon storage.

Objective 4: To study the influence of conjunctive use of residues and graded levels of N on crop yields and predominant N pools under sorghum-castor system.

- In order to achieve these objectives, soil quality assessment as influenced by different soil and nutrient management practices (Tillage, residue, INM treatments etc.) across rainfed agro ecology was under taken. In all, seven centers viz. Parbhani (Maharashtra), Dhantiwada (Gujarat), Agra (Uttar Pradesh), Hissar (Haryana), Hoshiarpur (Punjab), Arjia (Rajasthan), Rakhdhiansar (Jammu & Kashmir) of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) falling in different states and some of the on-going long term experiments on conservation agriculture and soil quality improvement were adopted for the study under National Fellowship Program. In addition to that , during the period of study, soil quality assessment was also under taken in an another on-going AP Cess fund program for other seven centres viz. Phulbani, (Orissa), Ranchi (Jharkand), Anantapur (Andhra Pradesh), Rajkot (Gujarat), Akola (Maharashtra), Kovilpatti (Tamilnadu) and Indore (Madhya Pradesh). For these centres also, predominant long term soil and nutrient management treatments were evaluated for their potential to aggrade / improve soil quality. Key indicators were identified for different cropping systems under different soil types. Soil quality indices (SQI) were also calculated to screen the best soil and nutrient management.
- Besides the studies undertaken for Centres, the three field experiments were also conducted at Hyderabad centre in Alfisol on soil quality restoration, assessment and improvement.
- Data set was generated for 21 soil quality variables (Physical, Chemical and Biological) through rigorous soil analysis.
- Key indicators of soil quality were identified for varying cropping system under different soils for all the eight locations using the ‘State of the Art’ methodology being followed at international level.
- **Annual reports along with (Statement of Expenditure) SOE were submitted to ADG (HRD), ICAR for all the years viz. 2005-06, 2006-07, 2007-08, 2008-09 for National Fellow Project.** Similarly, reports pertaining to AP Cess Fund Program were submitted to ADG (Agronomy), NRM, ICAR for the years (2005-06, 2006-07, 2007-08 along with a consolidated report (2005-08).

The salient findings of the studies are as follows:

Objective 1: To evaluate the long term influence of existing selected soil and nutrient management practices on soil quality parameters, to identify the key indicators and to compute the soil quality indices under different cropping systems in rainfed areas across the country.

Phulbhani Centre

Experiment 1: Organic farming comprising of INM treatments and legume based cropping systems

The four cropping systems adopted were: i) Sorghum + pigeon pea (4:2), ii) Soybean + pigeon pea (4:2), iii) Cotton + black gram (1:1) and iv) Mung bean + rabi sorghum.

b) Sorghum + pigeon pea (4:2) system

- The key soil quality indicators for sorghum + pigeon pea system were found to be organic carbon, available S, dehydrogenase assay, labile carbon and mean weight diameter.
- The soil quality indices varied from 1.68 to 2.47, while the relative soil quality indices (RSQI) varied from 0.66 to 0.97 across the INM treatments.
- Among all the INM treatments, significantly highest soil quality index was observed with application of FYM@ 5 t ha^{-1} (2.47) which was at par with 25% RDF + FYM@ 2.5 t ha^{-1} (2.43). It was observed that the treatments which received FYM had the highest soil quality which was followed by the treatments which received gliricidia biomass as nutrient component.
- Irrespective of their statistical significance, the relative order of performance of treatments in terms of influencing soil quality were: F1: FYM@ 5 t ha^{-1} (2.47) > F4: 25% RDF + FYM@ 2.5 t ha^{-1} (2.43) > F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1} (2.31) > F2: Gliricidia @ 3 t ha^{-1} (semi dried) (2.30) > F3: RDF (2.27) > Control with rotation (1.75) > Absolute control without rotation (1.68).
- The percent contributions of key indicators towards soil quality indices were: Mean weight diameter (29%), labile carbon (28%), dehydrogenase assay (26%), organic carbon (10%) and available S (7%).

ii) Soybean + pigeon pea (4:2) ssytem

- The key indicators for soybean + pigeon pea (4:2) system in Vertisol at Parbhani included pH, available S, dehydrogenase assay, labile carbon and mean weight diameter.

- Soil quality indices varied from 1.48 to 2.16 while the RSQI values varied from 0.68 to 0.99 across the INM treatments.
- The treatment which received FYM@ 5 t ha^{-1} maintained significantly highest soil quality index of 2.16 followed by the application of Gliricidia @ 3 t ha^{-1} (semi dried) (2.00).
- Irrespective of their statistical significance, the relative order of performance of treatments in terms of influencing soil quality was: F1: FYM@ 5 t ha^{-1} (2.16) > F2: Gliricidia @ 3 t ha^{-1} (semi dried) (2.00) > F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1} (1.97) > F4: 25% RDF + FYM@ 2.5 t ha^{-1} (1.90) > F3: RDF (1.79) Control with rotation (1.60) > Absolute control without rotation (1.48).
- The percent contributions of key indicators towards soil quality indices were: pH (7%), available S (8%), dehydrogenase assay (29%), labile carbon (31%) and mean weight diameter (25%).

iii) Cotton + black gram (1:1) system

- The key indicators for Cotton + Blackgram (1:1) system in Vertisol at Parbhani included pH, organic carbon, available K, available S, available Mn, dehydrogenase assay, labile carbon and mean weight diameter
- The soil quality indices varied from 2.07 to 2.49 while the RSQI values varied from 0.78 to 0.96 across the INM treatments.
- Significantly highest soil quality indices were observed with application of 25% RDF + FYM@ 2.5 t ha^{-1} (2.54) as well as Gliricidia @ 3 t ha^{-1} (semi dried) (2.51) which was at par with other treatments also.
- The relative order of performance of treatments in terms of influencing soil quality, irrespective of their statistical significance was: F4: 25% RDF + FYM@ 2.5 t ha^{-1} (2.54) > F2: Gliricidia @ 3 t ha^{-1} (semi dried) (2.51) > F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1} (2.49) > F3: RDF (2.43) F1: FYM@ 5 t ha^{-1} (2.48) > Control with rotation (2.15) > Absolute control without rotation (2.07).
- The percent contributions of key indicators towards soil quality indices were: pH (5%), organic carbon (21%), available K (4%), available S (5%), available Mn (21%), dehydrogenase assay (19%), labile carbon (20%) and mean weight diameter (5%).

iv) Mung bean + rabi sorghum system

- The key indicators for mung bean + rabi sorghum system in Vertisol at Parbhani were: available K, available S, available Mn, microbial biomass carbon as well as labile carbon.
- The soil quality indices varied from 2.00 to 2.70 while the RSQI values varied from 0.66 to 0.99 across the INM treatments.

- The treatments, which received FYM, showed the highest soil quality followed by the treatments, which received gliricidia biomass loppings.
- The order of performance and superiority of treatments in terms of influencing soil quality was : F1: FYM@ 5 t ha^{-1} (2.70) > F4: 25% RDF + FYM@ 2.5 t ha^{-1} (2.55) = F5: 25% RDF + Gliricidia @ 1.5 t ha^{-1} (2.55) > F2: Gliricidia @ 3 t ha^{-1} (semi dried) (2.47) > F3: RDF (2.36) > Control with rotation (2.08) > Absolute control without rotation (2.00).
- The percent contributions of key indicators towards soil quality indices were: available K (23%), available S (9%), available Mn (23%), microbial biomass carbon (21%) as well as labile carbon (24%).

Dantiwada Centre

Experiment 1: Long-term manurial trial under pearl millet system

- The key indicators for pearl millet system under Aridisols of Dantiwada were organic carbon, available N, exchangeable Ca and Mg, available Zn, labile carbon and bulk density.
- The soil quality indices varied from 1.77 to 2.46 and RSQI values when reduced to a scale of one varied from 0.71 to 0.99 across the long-term manurial treatments.
- , The relative order of performance and superiority of the treatments in influencing soil quality Index was: T5: 50 % RDN (urea) + 50% RDN (FYM) (2.46) > T4: 50 % RDN through FYM (2.37) > T6: Farmers method 5 t FYM ha^{-1} once in three years (2.31) > T2: 100 % RDN through urea (2.23) > T3: 50 % RDN through urea (2.00) > T1: Control (1.77).
- The average percent contribution of key indicators towards soil quality indices was: organic carbon (19.9%), available N (11.3%), exchangeable Ca (7.1%) and Mg (20.8%), available Zn (10.9%), labile carbon (17.7%) and bulk density (12.2%).

Agra Centre

Experiment 1: Long-term experiment in major production system

- The key soil quality indicators for pearl millet system under Entisols of Agra were: organic carbon, available N, exchangeable Ca, Available Zn and Cu, labile carbon and mean weight diameter.
- The soil quality indices varied from 2.33 to 3.47 while the RSQI values varied from 0.64 to 0.95 across the long-term integrated nutrient management treatments practiced for pearl millet system

- Among all the manurial treatments practiced, the application of 50% urea + 50% FYM showed the highest soil quality index of 3.47 which was at par with 100% RDF + 25 kg $ZnSO_4$ (3.20).
- Irrespective of their statistical significance, the relative order of performance of the INM treatments in influencing soil quality in terms of SQI was: T3: 50% urea + 50% FYM (3.47) > T4: 100% RDF + 25 kg $ZnSO_4$ (3.20) > T2: 50% urea + 50% Crop residue (3.01) > T5: Farmers method (2.77) > T1: Control (2.33).
- The quantum of percent contribution of key indicators towards soil quality indices was: organic carbon (19%), available N (20%), exchangeable Ca (3%), Available Zn (4%) and Cu (17%), labile carbon (20%) and mean weight diameter (17%).

Experiment 2: Tillage and nutrient management for resource conservation and improving soil quality

- The key soil quality indicators for pearl millet system under Entisols of Agra were: organic carbon, exchangeable Ca, available Zn, available Cu, dehydrogenase assay, microbial biomass carbon and mean weight diameter.
- The soil quality indices varied from 0.86 to 1.08 while the RSQI values varied from 0.72 to 0.90 across the tillage and nutrient management treatments practiced for pearl millet system
- Tillage as well as the nutrient management treatments played a significant role in influencing the soil quality indices while their interaction effects were not so conspicuous on soil quality indices.
- Among the tillage treatments, practice of low tillage with one interculture + weedicide application resulted in higher soil quality index of 0.98 followed by practice of conventional tillage + one interculture (0.94) which was at par with the practice of low tillage + one interculture (0.93).
- Among the nutrient management treatments, application of nutrients through 100% organic sources maintained highest soil quality with SQI value of 1.05 while the other two nutrient management practices viz., 50% N (organic) + 50 % (inorganic source) as well as 100% N (inorganic source) with SQI values of 0.92 and 0.88 respectively, maintained soil quality at par with each other.
- Irrespective of their statistical significance, the relative order of performance in influencing soil quality in terms of SQI was: CT + IC + 100% N (organic source/compost) (1.08) > LT + Weedicide + IC + 100% N (organic source/compost) (1.05) > LT + IC + 100% N (organic source/compost) (1.02) > LT + Weedicide + IC + 50% N (organic) + 50 % inorganic source) (0.99) > LT + Weedicide + IC + 100% N (inorganic source) (0.90) >

LT + IC + 100% N (inorganic source) (0.89) > CT + IC + 50% N (organic) + 50 % inorganic source) (0.88) = LT + IC + 50% N (organic) + 50 % inorganic source) (0.88) > CT + IC + 100% N (inorganic source) (0.86).

- The various key indicators which contributed towards soil quality indices were: organic carbon (17%), exchangeable Ca (10%), available Zn (9%), available Cu (6%), dehydrogenase assay (6%), microbial biomass carbon (25%) and mean weight diameter (27%).

Experiment 3: Farmers fields

- Three cropping systems selected under farmer's fields at Agra were evaluated for their performance in maintaining soil quality
- On the whole, it was observed that, except for available P, K, labile carbon and bulk density, the influence of cropping systems was not conspicuous on any of the soil quality parameters chosen under this study.
- The soils were neutral to slightly alkaline in reaction with pH varying from 7.05 to 7.68 and electrical conductivity ranging from 0.25 to 0.32 dSm^{-1}. Organic carbon as well as available N under these cropping systems was low ranging from 4.20 to 4.56 g kg^{-1} and 130.6 to 141.8 kg ha^{-1} respectively. On the other hand, available P was medium to high varying from 22.6 to 43.7 kg ha^{-1} while available K was medium varying from 183.2 to 271.1 kg ha^{-1} across the cropping systems. The status of available S as well as the micronutrient contents was satifactory in these soils.
- Among the biological soil quality parameters, dehydrogenase activity was quite good ranging from 7.21 to 9.04 μg TPF $hr^{-1}g^{-1}$ across the cropping systems, while the microbial biomass carbon values were recorded to be low as the analysis was carried out in relatively dry soil samples. On the other hand, labile carbon was significantly higher under pigeonpea + green gram system (263.1 μg g^{-1} of soil) followed by green gram and mustard system (235.6 μg g^{-1} of soil) while the lowest was recorded under pearl millet + cluster bean system (226.8 μg g^{-1} of soil).
- Contrarily, bulk density was lowest under pearl millet + cluster bean system (1.29 Mg m^{-3}) and was highest under green gram + mustard system (1.39 Mg m^{-3}).
- In this experiment, the influence of various cropping systems on soil quality parameters was found to be non-significant except available P, K, labile carbon and bulk density. Hence, soil quality indices could not be computed for these farmers' fields at this centre

Hissar Centre

Experiment 1: Integrated nutrient supply for rainfed semiarid tropics under pearl millet and mungbean system

- The key indicators for pearl millet -mung bean system included pH, available N, K, Zn, Cu and dehydrogenase activity . The soil quality indices varied from 1.11 to 1.52 and the RSQI values varied from 0.70 and 0.97 across the management treatments practiced for pearl millet and mung bean system.
- Application of 25 kg N through compost showed the highest soil quality index of 1.52 and its performance was observed to be almost at par with all the other treatments except control.
- Irrespective of their statistical significance, the relative order of performance in influencing soil quality in terms of SQI was: T3: 25 kg N (compost) (1.52) > T6: 15 kg N (compost) + 10 kg N (inorganic) + biofertilizer (1.49) > T5: 15 kg N (compost) + 10 kg N (GLM) (1.47) > T4: 15 kg N (GLM) + 20 kg N (inorganic) (1.46) > T2: 100 % N (inorganic) (1.45) and T1: Control (1.11**).**
- The magnitude and extent of contribution of key indicators towards soil quality indices was: available N (35%), available Zn (35%), available Cu (10%), pH (10%), available K (5%) and dehydrogenase assay (5%).

Experiment 2: Organic farming studies on rainfed mustard

- The key soil quality indicators identified for mustard system in Aridisols of Hissar included available P, exchangeable Mg, and available Zn & Fe.
- The soil quality indices varied from 0.71 to 1.04 and the RSQI values varied between 0.65 and 0.95 across the manurial treatments practiced for mustard system
- Among all the manurial treatments practiced, the application of FYM @ 4 t ha^{-1} showed the highest soil quality index of 1.04 and its performance was observed to be almost at par with all the treatments.
- , The relative order of performance in influencing soil quality in terms of SQI was: T2: FYM (4 t ha^{-1}) (1.04) > T5: Cowpea green manure (40 DAS) (1.00) > T3: Vermiculture (4 tha^{-1}) (0.95) > T4: Diancha Green manure (40 DAS) (0.89) > T1: Control (0.71).
- The average percent contribution of key indicators towards soil quality indices was: available Zn (63%), exchangeable Mg (13%), available Fe (11%) and available P (7%).

Experiment 3: Tillage and nutrient management strategies for resource conservation and improving soil quality and productivity of rainfed pearl millet

- The key indicators for rainfed pearl millet system in Aridisols at Hissar included EC, available N, exchangeable Mg, available Mn, DHA, MBC and BD. The soil quality indices varied from 1.50 to 1.74 while the RSQI values varied between 0.83 and 0.96 across the tillage and nutrient management treatments practiced for rainfed pearl millet system
- The practice of conventional tillage (CT) + two intercultures (IC) + 100% N (organic source/compost) and CT + two IC + 100% N (inorganic source) maintained the highest soil quality indices of 1.74 which was at par with other tillage and nutrient management practices.
- When averaged over the nutrient management treatments, practice of conventional tillage with two interculture operations performed better in maintaining significantly highest soil quality index of 1.74, while the practice of low tillage with two interculture operations or weedicide application + one interculture operation, both maintained the soil quality index of 1.60.
- The application of 100% N through organic sources recorded significantly highest SQI of 1.69 which was at par with the other treatments.
- Irrespective of their statistical significance, the relative order of performance in influencing soil quality in terms of SQI was: T1: CT + Two IC + 100% N (organic source/compost) (1.74) > T3: CT + Two IC + 100% N (inorganic source) (1.74) > T4: LT + Two IC + 100% N (organic source/compost) (1.70) > T8: LT + Weedicide + One IC + 50% N (organic) + 50 % inorganic source) (1.68) > T2: CT + Two IC + 50% N (organic) + 50 % inorganic source) (1.64) > T7: LT + Weedicide + One IC + 100% N (organic source/compost) (1.63) > T5: LT + Two IC + 50% N (organic) + 50 % inorganic source) (1.59) > T6: LT + IC + 100% N (inorganic source) (1.50) > T9: LT + Weedicide + One IC + 100% N (inorganic source) (1.50).
- The average percent contribution of key indicators towards soil quality indices was: EC (15%), available N (19%), exchangeable Mg (18%), available Mn (13%), dehydrogenase assay (19%), microbial biomass carbon (5%) and bulk density (11%).

Experiment 4: Cropping systems at Farmers fields

- The key soil quality indicators for different cropping systems practiced in farmers fields of Hissar included pH, available K, exchangeable Ca & Mg, available Cu, labile carbon and bulk density.

- The soil quality indices varied from 2.87 to 4.13 while the RSQI values varied between 0.65 and 0.93 across the farmer's fields.
- The undisturbed system had the highest SQI of 4.13. But among the cropping systems, the mung bean system had the highest SQI of 3.82.
- Irrespective of their statistical significance, the relative order of performance of the cropping systems in influencing soil quality in terms of SQI was: Undisturbed (4.13) > Mung bean (3.82) > Pearl millet- Fallow (3.00) > Fallow – Chickpea (2.87).
- The average percent contribution of key indicators towards soil quality indices was: pH (22%), available K (16%), exchangeable Ca (14%), exchangeable Mg (4%), available Cu (9%), labile carbon (15%) and bulk density (20%).

Hoshiarpur Centre

Experiment 1: Integrated nutrient management practices in maize/black gram – wheat/lentil cropping systems under rainfed semi-arid tropics

- The key indicators for different soil- nutrient management (INM) treatments under Maize-Wheat based cropping sequence in Inceptisols of Ballowal Saunkhri included available N, available P, available K, exchangeable Ca and microbial biomass carbon.
- The soil quality indices varied from 1.16 to 1.61 while the RSQI values varied from 0.70 to 0.98 across the treatments.
- Application of 25 kg N (compost) (1.61) as well as application of 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) both recorded the highest SQI of 1.61.
- Irrespective of their statistical significance, the relative order of performance of the nutrient management treatments in influencing soil quality in terms of SQI was: T4: 25 kg N (compost) (1.61) = T9: 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) (1.61) > T2: 100% RDN (80 kg N ha^{-1}) (1.48) > T6: 15 kg N (compost) + 20 kg N ha^{-1} (inorganic) (1.47) > T7: 15 kg N (green leaf) + 10 kg N ha^{-1} (inorganic) (1.46) > T5: 15 kg N (compost) + 10 kg N ha^{-1} (inorganic) (1.45) > T3: 50% RDN (80 kg N ha^{-1}) (1.41) > T8: 15 kg N (green leaf) + 20 kg N ha^{-1} (inorganic) (1.32) > T1: No Fertilizer (1.16).
- The average percent contribution of key indicators towards soil quality indices was: available N (13%), available P (32%), available K (34%), exchangeable Ca (9%) and microbial biomass carbon (12%).

Experiment 2: Effect of tillage and sources of nitrogen on the crop productivity in maize-wheat cropping sequence under dryland conditions

- The key soil quality indicators for different tillage and soil-nutrient management treatments under maize-wheat cropping sequence in Inceptisols of Ballowal Saunkhri, Hoshiarpur included viz., pH, electrical conductivity, organic carbon, available N, available P, exchangeable Mg and available S.
- In this experiment, the soil quality indices varied from 0.96 to 1.19 while the RSQI values varied between 0.80 and 0.99 across the tillage and nutrient management treatments.
- Tillage, nutrient management treatments as well as their interaction effects had significant influence on soil quality indices. Among the tillage treatments, practice of conventional tillage + one interculture maintained significantly highest soil quality with SQI of 1.12 which was almost at par with practice of 50% CT + one interculture + chemical weed control (1.08).
- Among the nutrient management treatments, application of nutrients through 50% N (organic) + 50 % (inorganic) source maintained higher soil quality with SQI of 1.10 followed by application of 100% organics (1.08).
- Of all the treatments, 50 % CT + IC + CWC + 50% N (organic) + 50 % (inorganic) source maintained highest soil quality with SQI of 1.19 which was at par with CT + IC + 100% N (organic source/compost) (1.16).
- The average contribution of key indicators towards soil quality indices was: pH (12%), electrical conductivity (6%), organic carbon (31%), available N (14%), available P (14%), exchangeable Mg (13%) and available S (10%).

Experiment 3: Farmer's fields

- The key soil quality indicators for different cropping systems practiced in farmer's fields in Inceptisols of Ballowal Saunkhri, Hoshiarpur included available N, available P, available K, exchangeable Mg, available S, Available Zn, available Mn and available B. It was surprised to observe that this MDS did not include any of the biological or physical soil quality indicators.
- The soil quality indices varied from 1.11 to 1.61 while the RSQI values varied from 0.67 to 0.98 across the farmer's fields. Maize-wheat system maintained the highest soil quality with SQI value of 1.61 followed by agroforestry (dhek) system (1.35).
- Irrespective of their statistical significance, the relative order of performance of the cropping systems in influencing soil quality in terms of SQI was: Maize- Wheat (1.61) > Agroforestry (Dhek) - Gnut/ Wheat/ Lentil/ Taramira (1.35) > Agri-Horti (Guava)- Gnut/ Barley/ Wheat / Lentil-Guava) (1.29) > Agri-Horti (Peach)- Gnut/Barley/Wheat

/Taramira) (1.24) > Agroforestry (Dhek)- Gnut/ Blackgram/ Bajra (F) (1.16) > Pearlmillet-Oilseed (1.11).

- The average percent contribution of key indicators towards soil quality indices was: available N (11%), available P (4%), available K (22%), exchangeable Mg (7%), available S (12%), Available Zn (8%), available Mn (10%) and available B (26%). Of all these indicators, available B contributed more to SQI followed by available K in these soils.

Arjia Centre

Experiment 1: Low till farming strategies for resources conservation and improving soil quality

- The key soil quality indicators for different tillage and soil-nutrient management treatments under Maize-Blackgram system in Inceptisols of Arjia included soil pH, organic carbon, available N, available Zn, available Fe, and labile carbon.
- The soil quality indices varied from 1.62 to 1.89 while the RSQI values varied from 0.84 to 0.98 across the tillage and nutrient management treatments.
- Tillage showed a significant influence while the nutrient management treatments did not show any significant influence in maintaining soil quality while their interaction effects had a significant influence.
- Among the tillage methods, practice of low tillage + herbicide + 1 weedicide + hoeing maintained significantly highest SQI of 1.84 followed by the other two methods.
- Of all the treatments, practice of LT + herbicide + 1 weedicide + hoeing + 100% inorganic N maintained significantly highest SQI of 1.89 which was at par with LT + herbicide + 1 weedicide + hoeing + 100% organic N (1.87).
- The average percent contribution of key indicators towards soil quality indices was: soil pH (8%), organic carbon (24%), available N (16%), available Zn (8%), available Fe (16%), and labile carbon (28%).

Experiment 2: Integrated nutrient supply system for rainfed semiarid tropics under maize, blackgram strip and block system

- Soils of the experimental field were found to be almost neutral in reaction tending towards salinity with pH of 7.25 to 7.32. Electrical conductivity of the soils ranged from 0.18 to 0.22 dS m^{-1} and organic carbon 3.9 to 4.7 g kg^{-1}.
- It was clearly observed that the macronutrient content i.e., available N, P and K content of the soils were not significantly influenced by the type of cropping systems. However,

available nitrogen in these systems ranged from 123.2 to 127.8 kg ha^{-1}, available phosphorus form 19.2 to 33.8 kg ha^{-1} and available potassium from 321.4 to 364.3 kg ha^{-1}.

- Exchangeable calcium in the soils was significantly influenced by the cropping systems and ranged from 7.8 to 16.8 cmol kg^{-1}. Among the systems, strip system of maize and black gram recorded the highest exchangeable calcium (16.8 kg cmol kg^{-1}) while blocks of black gram recorded the lowest (7.8 kg ha^{-1}). Exchangeable magnesium was also not significantly influenced by the management treatments. Available sulphur in these soils was significantly influenced by the cropping system and was found to be highest under strip system of maize-blackgram (10.88 kg ha^{-1}), while it was lowest under black gram block system (7.92 kg ha^{-1}).
- The cropping systems did not show any significant influence on the DTPA extractable micronutrients except Mn. However, Zn, Fe, Cu and B in these soils ranged from 1.59 to 1.78, 6.68 to 7.76, 2.6 to 3.5 and 0.72 to 0.80 µg g^{-1} of soil respectively. Strip system of maize-blackgram recorded significantly highest available Mn (13.65 µg g^{-1} of soil) while, blocks system of black gram recorded the lowest amount (6.59 µg g^{-1} of soil).
- There was no significant influence of crop blocks under maize-blackgram system on physical and biological soil quality parameters. However, dehydrogenase activity in the soil ranged from 1.19 to 2.09 µg TPF $hr^{-1}g^{-1}$, microbial biomass carbon from 108.4 to 115.7 µg g^{-1} of soil and labile carbon 291.0 to 303.8 µg g^{-1} of soil. The bulk density in the systems varied from 1.26 to 1.32 Mg m^{-3} while the mean weight diameter varied from 0.13 to 0.19 mm.
- As most of the soil quality parameters were not significantly influenced by the management treatments, soil quality assessment using principal component analysis was not done and soil quality indices could not be computed.

Experiment 3: Soil quality assessment under Farmers fields

- The key indicators for different cropping systems under farmers fields Inceptisols of Arjia included six soil quality variables viz., organic carbon, exchangeable Ca, available Fe, dehydrogenase assay, labile carbon and bulk density.
- The soil quality indices varied from 2.77 to 3.53 while the RSQI values varied from 0.76 to 0.98 across the various cropping systems under farmers fields.
- Among the cropping systems, groundnut-sesame system maintained highest soil quality index (3.53) and was at par with maize-blackgram system (3.38) while groundnut-taramira system maintained the lowest SQI of 2.77.

- The relative order of performance of management treatments in influencing soil quality indices, was: Groundnut- Sesame (3.532) > Maize-Blackgram (3.375) > Groundnut-Taramira (2.765).
- The average percent contribution of key indicators towards soil quality indices was: organic carbon (20%), exchangeable Ca (18%), available Fe 92%), dehydrogenase assay (14%), labile carbon (23%) and bulk density (23%).

Rakhdhiansar Centre

Experiment 1: Integrated nutrient supply system for rainfed semi-arid tropics

- The six key soil quality indicators for maize-black gram system practiced in Inceptisols of Rakhdhiansar included exchangeable Ca, available N, available Zn, & B, microbial biomass carbon and bulk density.
- Soil quality indices varied from 2.68 to 4.17 while the RSQI varied from 0.63 to 0.97 across the integrated nutrient management treatments.
- Application of 25 kg N compost had significantly highest RSQI of 0.97 which was at par with application of 15 kg N (compost) + 20 kg N (inorganic) (0.94).
- Irrespective of their statistical significance, the relative order of performance of the treatments in influencing the soil quality indices were: T4: 25 kg N (compost) (4.17) > T6: 15 kg N (compost) + 20 kg N (inorganic) (4.05) > T5: 15 kg N (compost) + 10 kg N (inorganic) (3.75) > T2: 100 % N (inorganic) (3.55) > T3: 50 % N (inorganic) (3.46) > T1: Control (2.68).
- The contribution of key indicators towards soil quality was: available N (3.49%), exchangeable Ca (19.6%), available Zn (16.6%), available B (19.3%), microbial biomass carbon (19.7%), bulk density (21.4%).

Experiment 2: Permanent manurial trial in maize crop

- The key soil quality indicators identified for maize system in Inceptisols of Rakhdhiansar were: pH, EC, organic carbon, available P, available S, available Zn, dehydrogenase assay and microbial biomass carbon.
- The manurial treatments had significant influence on soil quality indices, which varied from 0.97 to 1.52 across the management treatments, while the relative soil quality indices varied from 0.62 to 0.98.
- Of the different manurial treatments applied to maize crop, application of 50%N (FYM) as well as application of 50% NPK + 50% N (FYM) performed equally well in maintaining

the soil quality with a SQI value of 1.52 and these were at par with 50% NPK + 50% N (Crop residue) (1.46). However, the control plot recorded the lowest RSQI of 0.97.

- Irrespective of their statistical significance, the relative order of performance of the manurial treatments in terms of influencing soil quality indices were: T5: 50%N (FYM) (1.52) > T7: 50% NPK + 50% N (FYM) (1.52) > T6: 50% NPK + 50% N (Crop residue) (1.46) > T2: 100% NPK (60:40:20 kg ha^{-1}) (1.38) > T3: 50% NPK (1.33) > T4: 50%N (crop residue) (1.25) > T1: Control (0.97).
- The percent contribution of key indicators towards soil quality indices was computed and it was observed that among all the key indicators, available S and microbial biomass carbon contributed a maximum percentage of 31.9 and 31.8% respectively while the other indicators which contributed relatively less were: pH (8.05%), EC (6.01%), organic carbon (4.87%), available P (4.45%), available Zn (4.56%) and dehydrogenase assay (8.36%).

Experiment 3: Nutrient management in maize- wheat rotation

- The key soil quality indicators under maize-wheat rotation included organic carbon, available N, available P, available K, available Fe & Zn, microbial biomass carbon, bulk density and mean weight diameter.
- The nutrient management treatments significantly influenced the soil quality indices which varied between 3.69 to 5.66 across the management treatments while the relative soil quality indices varied between 0.63 to 0.96.
- Of all the nutrient management treatments, application of FYM @ 10 t ha^{-1} + 40 kg N ha^{-1} maintained significantly highest SQI of 5.66 which was at par with application of FYM @ 10 t ha^{-1} + 30 kg N ha^{-1} and green manuring with Sunhemp + 20 kg N ha^{-1} both of which maintained SQI of 5.40.
- Irrespective of their statistical significance, the relative order of performance of the nutrient management treatments in maintaining the soil quality indices were: T4: FYM @ 10 t ha^{-1} + 40 kg N ha^{-1} (5.66) > T5: Green manuring with Sunhemp + 20 kg N ha^{-1} (5.44) > T3: FYM @ 10 t ha^{-1} + 30 kg N ha^{-1} (5.40) = > T2: FYM @ 10 t ha^{-1} + 20 kg N ha^{-1} (5.16) > T1: Control (3.69).
- The percent contributions of each of these key indicators towards soil quality indices were also computed. It was observed that almost all the key indicators contributed more or less equally towards the soil quality indices except available N and available Fe, which contributed to a minimum extent of 2.27 % and 1.90% respectively. The percent contribution of the other key indicators was as follows: organic carbon (13.8%), available

P (13.4%), available K (14.5%), available Zn (12.6%), microbial biomass carbon (13.7%), bulk density (16.2%) and mean weight diameter (11.6%).

Experiment 4: Tillage and nutrient management for resource conservation and improving soil quality.

- The key soil quality indicators for maize cropping system in Inceptisols of Rakhdhiansar included available P, available S, available Zn & B, labile carbon and mean weight diameter.
- Tillage treatments did not show any significant influence in improving the soil quality while the nutrient management treatments played a significant role in maintaining the soil quality. The soil quality indices varied between 1.28 to 1.58 while the relative soil quality indices varied between 0.79 to 0.97 across the management treatments.
- Among the nutrient management treatments, application of 100% N through organic sources maintained significantly highest soil quality (1.52) followed by application of 50% N through organic sources + 50 % N through inorganic sources (1.36) which was at par with the application of 100% N through inorganic sources (1.33).
- The percent contribution of these key indicators towards soil quality indices was as follows: available P (11.0%), available S (7.23%), available Zn (8.99%), available B (23.3%), labile carbon (26.6%) and mean weight diameter (22.9%).

Experiment 5: Farmers Fields

- The cropping systems practiced in farmer's fields when statistically tested for their influence on soil quality parameters proved insignificant for almost all the parameters except for dehydrogenase activity as well as microbial biomass carbon.
- However, soils under these cropping systems were near neutral to neutral in reaction with EC ranging from 0.18 to 0.21 dS m^{-1}. Organic carbon was observed to be low in these cropping systems varying from 3.90 to 4.11 g kg^{-1}. Among the macronutrients, available N was very low in these soils (142.2 to 167.2 kg ha^{-1}) while available P and K were high and medium with values ranging from 24.8 to 35.2 kg ha^{-1} and 249.0 to 283 kg ha^{-1} respectively across the cropping systems.
- Exchangeable Ca and Mg were found to be adequate ranging from 3.68 to 4.69 cmol kg^{-1} and 0.69 to 0.98 cmol kg-1 respectively across the various cropping systems. Available S was medium to high in these soils ranging from 14.3 to 18.0 kg ha^{-1}. Among the micronutrients, all the micronutrients viz., Zn, Fe Mn and B were observed to be high in these soils ranging from 1.17 to 1.34, 9.50 to 11.7, 12.5 to 14.7 and 0.73 to 0.88 μg g^{-1}

respectively while Cu was medium (0.53 to 0.67 μg g^{-1}) across the different cropping systems under farmers fields.

- Among the biological soil quality parameters, dehydrogenase activity as well as microbial biomass carbon was significantly influenced by the cropping systems practiced while labile carbon content was not conspicuously influenced. Dehydrogenase activity varied from 2.75 to 4.69 μg TPF $hr^{-1}g^{-1}$ across the cropping systems and significantly highest DHA was recorded under blackgram- wheat system (4.69 μg TPF $hr^{-1}g^{-1}$) followed by Maize-Wheat system (3.94 μg TPF $hr^{-1}g^{-1}$) while maize-toria-wheat system recorded the lowest (2.75 μg TPF $hr^{-1}g^{-1}$). Microbial biomass carbon was significantly highest under pearl millet-wheat system (206.6 μg g^{-1} of soil), which was at par with maize-toria-wheat system (199.9 μg g^{-1} of soil). Labile carbon varied between 323.7 to 360.7 μg g^{-1} of soil across the cropping systems and was not significantly influenced.
- Bulk density under these cropping systems ranged from 1.40 to 1.45 Mg m^{-3} while the mean weight diameter varied from 0.22 to 0.29 mm and were not influenced by the cropping systems.
- As majority of the soil quality indicators studied in farmer's fields were not significantly influenced by the cropping systems, soil quality indices could not be computed.

Assessment of chemical soil quality in rainfed farmers fields of Ranga Reddy district of Andhra Pradesh

- Study was initiated with the objective to assess soil quality in rainfed farmer's fields and develop soil chemical quality index in collaboration with Krishi Vigyan Kendra (KVK) of this Institute under Frontline Demonstration experiments on Maize. Soil samples collected by KVK centre from 338 rainfed farmer's fields representing two mandals (Shabad and Kandukur) covering 8 villages (Bobbligum, Pulimamidi, Moddemguda, Pochammathanda, Pulimamidi, Saireddyguda, Saralaraopalli and Thandamucherla) of Rangareddy district predominantly representing two soil types (Black and red) were analyzed for 13 soil chemical health indicators (pH, EC, OC, available N, P, K, exchangeable Ca, Mg, DTPA extractable Zn, Fe, Cu, Mn and DTPA-sorbitol extractable boron).
- The results were processed and a computer generated soil chemical health test reports with specific indications and suggestions were prepared with the help of other associated Scientist and programmer of the institute and issued to KVK section for distribution to the farmers. A sample of computer generated soil chemical health report is appended.

Objective 2: To evaluate the low-cost integrated nutrient management (INM) treatments (comprising of farm based organics) under conventional and reduced tillage in sorghum-mung bean strip cropping system in terms of sustainability of crop yields and long term effects on soil quality in Alfisol

- An on going experiment which was started during 1998 was adopted for the study. During the period of this report also field experiment were conducted. Pooled analysis of grain yield data of sorghum as influenced by tillage and INM treatments was done for a period of ten years.

Sorghum grain yields

- Over ten years of experimentation, the nutrient management treatments showed a significant influence on sorghum grain yields. Out of these ten years period, significantly highest sorghum grain yields were observed during the year 2002 (1929 kg ha^{-1}) followed by the year 2004 (1682 kg ha^{-1}) while the lowest yields were observed during the year 2005 (1165.3 kg ha^{-1}).
- On an average, over the years, conventional tillage performed significantly well in maintaining higher sorghum grain yield (1592.7 kg ha^{-1}) which was 14% higher compared to the minimum tillage practice (1397.2 kg ha^{-1}).
- Among the nutrient management treatments, when averaged over years as well as tillage, , application of 2 t Gliricidia loppings + 20 kg N through urea to sorghum crop recorded significantly highest sorghum grain yield of 1706.3 kg ha^{-1} followed by both application of 4 t compost + 20 kg N through urea (1664.9 kg ha^{-1}) as well as 40 kg N through urea (1648.5 kg ha^{-1}) and were at par with each other.
- When compared to control, the percent increase in sorghum grain yields under all the nutrient management treatments were: T4 =2 t Gliricidia loppings + 20 kg N through urea (98.8%) > T3 = 4 t compost + 20 kg N through urea (94.0%) = T2 = 40 kg N through urea (92.1%) > T5 = 4 t compost + 2 t gliricidia loppings (86.1%).

Mungbean grain yields

- As in case of sorghum, pooled analysis of grain yield data of mungbean as influenced by tillage and INM treatments was also done for a period of ten years.
- Over a period of ten years, tillage as well as the nutrient management treatments played a significant influence on mungbean grain yields. Out of the ten years of experimentation, mung bean grain yields were highest (1204 kg ha^{-1}) during the year 2004 followed by the yields during the year 2007 (1030 kg ha^{-1}) while the lowest grain yields were recorded during the year 2000 (459.4 kg ha^{-1}).

- Of the two tillage methods, when averaged over the nutrient management treatments for a period of ten years, conventional tillage showed significantly higher mung bean grain yields (876.5 kg ha^{-1}) compared to minimum tillage (814 kg ha^{-1}).
- The percent increase in mungbean grain yields under conventional tillage was to the extent of 8% over minimum tillage. Among the nutrient management treatments, when averaged over the tillage, application of 2 t compost + 10 kg N through urea recorded significantly highest mung bean grain yields (937.2 kg ha^{-1}) and was at par with other two treatments, viz., 2 t compost + 1 t gliricidia loppings (934 kg ha^{-1}) and 1 t Gliricidia loppings + 10 kg N through urea (926 kg ha^{-1}).
- When compared to control, the percent increase in mungbean grain yields under all the nutrient management treatments were: T3 = 2 t compost + 10 kg N through urea (61.9%) = T5 = 2 t compost + 1 t gliricidia loppings (61.3%) = T4 =1 t Gliricidia loppings + 10 kg N through urea (60.0%) > T2 = 20 kg N through urea (46.9%).
- The long-term yield trends of mung bean as influenced by tillage and INM treatments revealed that after tenth year of the study, the performance of reduced tillage on an average, was almost near to that of conventional tillage. This trend indicated that in case of legume like mung bean, the probability of success of reduced tillage is quite higher in rainfed Alfisol soil which is susceptible to hard setting and compaction. Hence, this finding raises the hope of success of reduced tillage practices in rainfed semi-arid tropical soils.

Sustainability Yield Indices (SYI) and Agronomic Efficiency (AE)

- For sorghum crop, the sustainability yield indices varied from 0.27 to 0.67 while the agronomic efficiency ranged from 18.1 to 23.8 kg grain kg^{-1} N across the management treatments under both conventional and reduced tillages. When averaged over the treatments, conventional tillage maintained the highest SYI (0.57) as well as agronomic efficiency (17.2 kg grain kg^{-1} N) compared to minimum tillage with an average SYI of 0.47 and agronomic efficiency of 14.7 kg grain kg^{-1} N. When averaged over the tillage effects, application of 2 t Gliricidia loppings + 20 kg N through urea maintained the highest SYI (0.60) as well as agronomic efficiency (21.2 kg grain kg^{-1} N) followed by other treatments. Among all the treatments, practice of conventional tillage + application of 2 t Gliricidia loppings + 20 kg N through urea in case of sorghum crop recorded significantly highest SYI (0.67) as well as AE (23.8 kg grain kg^{-1} N).

- For mungbean crop, the sustainability yield indices varied from 0.26 to 0.52 while the agronomic efficiency varied from 13.0 to 19.3 kg grain kg^{-1} N across the management treatments under both conventional and minimum tillage plots. Similarly, in case of mung bean also, when averaged over the treatments, conventional tillage maintained higher SYI (0.47) as well as agronomic efficiency (13.7 kg grain kg^{-1} N) as compared to minimum tillage which maintained SYI of 0.39 and AE of 12.9 kg grain kg^{-1} N.

- When averaged over the tillage effects, both application of 2 t compost + 1 t gliricidia loppings as well as 2 t compost + 10 kg N through urea more or less maintained similar level of SYI and AE compared to other treatments. Among all the treatments, practice of conventional tillage + 2 t compost + 1 t gliricidia loppings maintained higher SYI (0.52) while practice of conventional tillage +2 t compost + 10 kg N through urea maintained higher agronomic efficiency (19.2 kg grain kg^{-1} N) under mung bean crop.

Assessment of soil quality

- Based on the series of analytical data screening steps, available N, Zn, Cu, MBC, MWD and HC were declared as the key indicators for Alfisol under sorghum - mung bean system under conventional and reduced tillage. The SQI varied from 0.66 (control) to 0.86 (4 Mg compost + 20 kg N through urea) under conventional tillage, while under reduced tillage, it varied from 0.66 (control) to 0.89 (4 Mg compost + 2 Mg gliricidia loppings).
- Tillage alone did not show any significant effect on SQI, while the conjunctive nutrient use treatments significantly influenced the SQI in these SAT Alfisols. Among all the treatments, when averaged over tillage, application of 4 Mg compost + 2 Mg gliricidia loppings showed the highest SQI (0.87) followed by 2 Mg gliricidia loppings + 20 kg N through urea (0.84) which was at par with 4 Mg compost + 20 kg N through urea (0.82).
- The interaction effects of tillage and conjunctive nutrient use treatments were also found significant on SQI. On an average, under both CT and RT, the sole organic treatment out-performed in aggrading the soil quality to the extent of 31.8 % over control. The conjunctive nutrient use treatments aggraded the soil quality by 24.2 to 27.2 %, while the sole inorganic treatment could aggrade only to the extent of 18.2 % over the control.
- Interestingly, even the control which did not receive any N input in the form of treatment, except phosphorus, also maintained SQI of as high as 0.66. This may be attributed to the beneficial effect of legume crops grown in rotation with cereals, as various rotations, mainly cereal/legumes, combined with reduced tillage, could influence soil organic matter and associated aggregation and related hydraulic properties. In the present study, the overall order of superiority of the treatments from the viewpoint of soil quality indices was: T5>T4 = T3> T2>T1.
- The order of importance of the key indicators in influencing soil quality was MBC (0.41) = available N (0.41) > DTPA- Zn (0.37) > DTPA- Cu (0.12) > HC (0.09) > MWD (0.04) with a corresponding contribution of 28.5%, 28.6%, 25.3%, 8.6%, 6.1% and 2.9%

respectively in these soils. This showed that these key indicators have considerable role to play in influencing various soil functions and in turn the functional goals.

Carbon pools as influenced by INM and tillage practices under sorghum- green gram strip cropping after eight years of study (during 2006)

- After eight years of the study, various pools of carbon viz., organic carbon, inorganic carbon, microbial biomass carbon, oxidizable carbon, particulate organic carbon and total carbon as influenced by tillage and INM treatments were estimated using standard procedures.
- ❖ Irrespective of the treatments, minimum tillage plots recorded significantly higher total organic carbon (TOC) of 6.1 and 6.0 g kg^{-1} at both surface and subsurface layers than the conventionally tilled plots. When averaged over tillage, sole application of organics viz., 4 t compost + 2 t gliricidia loppings recorded the highest organic carbon content of 6.4 and 6.2 g kg^{-1} at surface and sub surface depths respectively. In this experiment, tillage did not show any significant influence on the microbial biomass carbon content at both surface and subsurface depths.
- ❖ The INM treatments had significant influence on $KMnO_4$ oxidizable carbon (LC) at the surface depth only. Among all the treatments, 2 t gliricidia loppings + 20 kg N through urea recorded the highest oxidizable carbon of 310.3 mg kg^{-1} which was at par with 4 t compost + 2 t gliricidia loppings (299.7 mg kg^{-1}) at surface depth.
- ❖ Particulate organic matter (POC) is a fraction of soil organic matter (SOM) that has the potential to serve as an indirect measure of soil health. This fraction plays an important role in soil aggregation either directly or indirectly by serving as a substrate for microbial activity. It is an important measure of soil health because its turn over time allows enough sensitivity to detect changes within a few years.
- ❖ Tillage showed significant influence on the particulate organic carbon at surface depth only but not at sub-surface depth. Among the treatments, when averaged over tillages, 4 t compost + 2 t gliricidia loppings recorded significantly highest amount of particulate organic carbon content of 4.5 g kg^{-1} at surface depth while under subsurface depth, 4 t compost + 20 kg N through urea recorded the highest particulate organic carbon content of 4.0 g kg^{-1} respectively.
- ❖ In low tillage, POC constituted 63.49 to 74.59 % of total organic carbon (TOC) in surface soil layer (0-5cm) and 48.51 to 77.84 % in subsurface soil layer (5-20 cm). In conventional tillage, the corresponding contribution of POC was 68.52 to 71.22 % and 54.13 to 73.78 % in surface and subsurface depths respectively.

Enzymatic activity as influenced by INM and tillage practices under sorghum- green gram strip cropping (during 2006)

- Minimum tillage proved significantly superior in influencing the dehydrogenase activity in the soils compared to conventional tillage. In minimum tillage, the dehydrogenase activity was 3.83 and 3.34 µg TPF g^{-1} hr^{-1} under surface and subsurface depths respectively.
- Among the treatments, when averaged over the tillage, 2 t Gliricidia loppings + 20 kg N through urea recorded significantly highest dehydrogenase activity of 4.5 µg TPF g^{-1} hr^{-1}which was at par with 4 t compost + 2 t gliricidia loppings (4.3 µg TPF g^{-1} hr^{-1}) at surface depth.
- Sulphatase enzyme has been reported to help in releasing plant available $S0_4$ from organic matter. Tillage did not influence the arylsulphatase activity, whereas, treatments had significant effect Significantly highest activity of arylsulphatase was recorded in 4 t compost + 20 kg N through urea (57.71 µg PNP g^{-1} hr^{-1}) at surface depth, while 2 t Gliricidia loppings + 20 kg N through urea showed significantly highest arylsulphatase activity (55.70 µg PNP g^{-1} hr^{-1}) at subsurface depth.
- The results of the present study will be useful in identifying most effective soil-nutrient management and tillage treatment for further recommendation. In the present study, we are focusing on long term experiments across the rainfed agro-ecology as well as farmers fields. The data so generated from both the situations would be effectively utilized for recommending soil-nutrient management strategies.

Objective 3: To study the response of sorghum-cowpea system to graded level of surface residue application under minimum tillage in Alfisol and effects on carbon storage.

Effect on Crop yields

- Sorghum grain yields in the first year of the experiment varied from 1396 to 1549 kg ha^{-1} and did not show much significant effect of different treatments. However, application of 6 t ha^{-1} of sorghum stover recorded the highest grain yield of 1549 kg ha^{-1} followed by application of 2t ha^{-1} of sorghum stover (1501 kg ha^{-1}).
- Since, this experiment has been planned on long-term basis to sequester/ store more and more carbon by making the soil as a sink, the intensive soil studies have been planned in the future. The CO_2 fluxes emitted through soil respiration was also periodically assessed.

- During the second year, the cowpea biomass yield was severely affected by hard setting and compaction due to zero tillage and varied from 228 to 319 kg ha^{-1}.
- The highest yield of above ground dry biomass of cowpea was recorded in plots which received of 4 t ha^{-1} of sorghum residue as surface application which was at par with 2 t ha^{-1} of sorghum residue (312 kg ha^{-1}). Horse gram grain and husk yields were significantly influenced by different residue levels and varied from 196 to 290 kg ha^{-1} and 126 to 179 kg ha^{-1} respectively.
- Sorghum residue applied @ 6 t ha^{-1} did not adversely affect the yield of the second crop and recorded the highest horse gram pod yield (468 kg ha^{-1}), grain yield (290 kg ha^{-1}) and husk yield (179 kg ha^{-1}). This treatment was followed by 4 t ha^{-1}. Weed growth and less water intake in the profile under zero tillage adversely affected the crop. Further, the less aeration of the root zone due to zero tillage also might have affected the plant growth.
- During the third year the sorghum grain yields varied from 1878 to 2242 kg ha^{-1} across the treatments. Surface application of 6 t ha^{-1} of sorghum residue recorded significantly highest sorghum grain yield of 2242 kg ha^{-1} which was at par with application of 4 t ha^{-1} of sorghum residue (2020 kg ha^{-1}).
- It was interesting to note that the increase in sorghum grain yield with surface application of 6 t ha^{-1} of sorghum residue and 4 t ha^{-1} of sorghum residue were 19.8 % and 7.98% respectively over no residue application (control). This indicated the importance of surface residue management in these moisture stressed hard setting soils. The beneficial effects of surface applied residues could be on several accounts such as reducing the water losses due to evaporation, keeping the soil temperature low, enhancing the microbial activity, more recycling of nutrients, protecting the soil from water erosion by way of intercepting the rain drops, etc.
- During the fourth year application of sorghum crop residue as surface mulch in combination with N @ 30 kg ha^{-1} and 30 kg P_2O_5 ha^{-1} under minimum tillage conditions significantly increased the cowpea (C 152) grain yield with sorghum residue applied as surface mulch @ at 4t ha^{-1}. The increase in grain yield of cowpea with residue application @ 2, 4 and 6 t ha^{-1} was to the tune of 20.7, 56.0 and 33.9% respectively over control.
- Carbon stocks as influenced by residue loading, minimum tillage, crop stubble retention and cropping system will be computed after fifth year of the study.

Effect of surface crop residue application on the carbon pools

- In order to study the influence of surface residue application under conservation tillage on carbon pools viz., microbial biomass carbon (MBC), 0.01 N $KMnO_4$ extractable labile C ($KMnO_4$ - LC), particulate organic carbon (POC), Inorganic C (IC), total organic carbon

(TOC), soil samples from two depths (0-5, 5-20) were collected after the harvest of the 1st crop of sorghum (2005) and were analyzed using standard procedures. The salient findings of the study were as follows.

- ❖ Based on the data generated after the 1st year of the experiment, it was observed that, except microbial biomass carbon, the other pools were not significantly influenced by the application of various levels of sorghum residues + 60 kg N ha^{-1} applied to previous crops + minimum tillage at both surface (0-5 cm) and sub-surface (5-20 cm) depths.
- ❖ Total Organic carbon (TOC) ranged from 4.2 to 5.2 g kg^{-1} at 0-5 cm depth and 3.8 to 4.8 g kg^{-1} at 5-20 cm depth. Whereas, inorganic carbon in the corresponding soil depths varied between 2.3 to 2.6 g kg^{-1} and 2.3 to 2.6 g kg^{-1} respectively. Interestingly, organic carbon content decreased in the lower depth while inorganic carbon was relatively higher.
- ❖ Microbial biomass carbon (MBC) is an important indicator of soil quality and is a measure of the living component of soil organic matter, except macro fauna and plant roots. In the present study, it ranged from 89.47 to 177.11 μg g^{-1} of soil at 0-5 cm depth and 76.93 to 167.83 μg g-1 of soil at 5-20 cm depth. Among the residue levels applied to the first crop (sorghum), application of 6 t ha^{-1} of sorghum stover recorded significantly highest microbial biomass carbon of 177.11 and 167.83 μg g^{-1} of soil at 0-5 and 5-20 cm respectively. The content of MBC in plots amended with 2 and 4 t ha^{-1} of residue almost remained same.
- ❖ The 0.01 N $KMnO_4$ oxidizable organic carbon is considered as a good measure of labile carbon or active carbon in soil. In this study, it ranged from 309.39 to 344.34 and 299.16 and 340.39 μg g^{-1} of soil at 0-5 and 5-20 cm depths respectively, and was not significantly affected by the management treatments.
- ❖ Similarly, particulate organic carbon (POC) and total carbon (TC) in the soils were also not significantly affected by the management treatments. However POC contents varied between 3.1 to 3.8 g kg^{-1} at 0-5 cm depth and 2.8 to 3.4 g kg^{-1} at 5-20 cm depth. Data indicated that POC content was relatively higher in surface layer than sub surface layer. It constituted about 63.49 to 74.49 and 48.51 to 77.84 % of TOC in surface and sub surface respectively.
- ❖ The extent of TC was to the tune of 6.5 to 7.8 and 6.3 to 7.4 g kg^{-1} at 0-5 and 5-20 cm depths respectively. Except inorganic carbon, all other carbon pools tended to decrease in sub-surface soil layer.

Effect of residue application on soil enzyme activity

- ❖ Soil enzymes are considered as one of the important biological soil quality indicators sensitive to management. Considering this, besides dehydrogenase, arylsulphatase, urease and phosphatases were studied during the period under report. Activity of all the enzymes studied was found to be significantly influenced by the management treatments and the data indicated the reduction in the activity of these enzymes in the lower depth (5-20 cm) of the soil compared to the surface 0-5 cm depth.

- Application of 6 t ha^{-1} of sorghum residue recorded the highest dehydrogenase assay of 2.49 at 0-5 cm depth, which was followed by the application of 4 t ha^{-1} of sorghum residue, while the control plot recorded the lowest assay. At 0-5 cm depth, significantly highest arylsulphatase activity of 174.41 μg PNP g^{-1} hr^{-1} was recorded under sorghum residue application @ 6 t ha^{-1} followed by 4 t ha^{-1}.
- Surface application of 6 t ha^{-1} of sorghum residue recorded the highest urease activity of 62.01 and 53.55 μg NH4 g^{-1} hr^{-1} at 0-5 and 5-20 cm depths respectively, which was followed by that of 4 t ha^{-1} of sorghum stover.
- Studies indicated that acid phosphatases (Ac-P) ranged from 179.8 to 549.5 and 128.1 to 458.2 μg PNP g^{-1} hr^{-1} at 0-5 cm and 5-20 cm depths respectively across the treatments. The significant highest Ac-P activity of 549.50 and 458.20 μg PNP g^{-1} hr^{-1} was recorded under surface application of 6 t ha^{-1} sorghum residue at both the depths respectively, followed by 4 t ha^{-1} of sorghum residue application. Application of 6 t ha^{-1} sorghum residue accounted for an increase of 205.57 % and 257.69 % over control at 0-5 cm and 5-20 cm depths respectively.
- The alkaline phosphatase activity (Alk-P) showed a trend similar to Ac-P activity. The significantly highest Alk-P activity of 400.3 and 328.0 μg PNP g^{-1} hr^{-1} was recorded under application of 6 t ha^{-1} sorghum residue at 0- 5 cm and 5- 20 cm depths respectively followed by 4 t ha^{-1} of sorghum residue application. Application of 6 t ha^{-1} sorghum residue recorded an increase of 376.2 % and 514.7 % over control in 0-5 cm and 5-20 cm depths respectively.
- The present study clearly indicated that acid and alkaline phosphatases activity increased with graded levels of residue application and tended to decrease with depth.

Effect of residue application on CO_2 emissions

- The CO_2 emissions were measured in this experiment which received sorghum residue @ 0, 2, 4 and 8t ha^{-1} as surface mulch as treatments and 60 Kg N ha^{-1} as uniform dose to sorghum crop in all the plots. Different level of residues significantly influenced the CO_2 emission. The emission rates increased with the amount of residue applied up to 4 t ha^{-1}on most of the Julian dates (between 315th to 30th Julian day). These studies will be of immense importance in computation of C balance, sink and stocks in soil and to develop management strategies for enhancing the level of SOC in these soils, which are mostly at the verge of degradation. The methods of measurements of CO_2 flux need to be improved using automatic CO_2 Flux Meters using IRGA (infrared gas analyzers) technique. These studies will be further continued.

Objective 4: To study the influence of conjunctive use of residues and graded levels of N on crop yields and predominant N pools under sorghum-castor system.

Sorghum grain yields

- Since the initiation of the experiment (1995), sorghum and castor were grown in rotation. During the period from 1995 to 2008, sorghum crop was grown during the years 1995, 1997, 1999, 2001, 2003, 2005, and 2007. In the year 2003, crop failed due to severe drought spell.
- Of the tillages, on an average, conventional tillage out performed over the minimum tillage in recording the sorghum grain yields during all the years. The average sorghum grain yields under conventional tillage were 1248 kg ha^{-1} while under minimum tillage it was 957 kg ha^{-1} amounting to 30.4% increase over the minimum tillage.
- Among the residues applied, gliricidia application outperformed the other two residue treatments and recorded sorghum grain yields to the extent of 1156 kg ha^{-1}, followed by sorghum stover application (1094 kg ha^{-1}) and no residue application (1058 kg ha^{-1}).
- Average sorghum grain yields showed a tremendous response towards the application of N levels and it was observed that the yields increased with increase in N level gradient. The average sorghum grain yields with the respective N levels were: 1425 kg ha^{-1} with 90 kg ha^{-1}, 1292 kg ha^{-1} with 60 kg N ha^{-1}, 1067 kg ha^{-1} at 30 kg N level while at 0 level, the yields were only to the extent of 626 kg ha^{-1}.
- The increase in sorghum grain yields over the 0 level was to the extent of 70.4%, 106.4 % and 127.6 % at 30, 60 and 90 kg levels respectively.

Castor crop yields

- During the period from 1995 to 2008, castor crop was grown only during the years 1996, 1998, 2000, 2002, 2004, 2006 and 2008. Statistical analysis of the data revealed a significant influence of years, tillage, residues as well as the N levels on castor pod yields. Of the tillages, on an average, conventional tillage out performed over the minimum tillage in recording the castor bean yields during all the years.
- The average castor bean yields under conventional tillage were 826 kg ha^{-1} while under minimum tillage it was 526 kg ha^{-1} amounting to 57.0 % increase over the minimum tillage. Among the residues applied, gliricidia application outperformed the other two

residue treatments and recorded castor bean yields to the extent of 726 kg ha^{-1}, followed by sorghum stover application (666 kg ha^{-1}) and no residue application (638 kg ha^{-1}).

- ❖ Average castor bean yields showed a tremendous response towards the application of N levels and it was observed that the yields increased with increase in N level gradient. The average castor bean yields with the respective N levels were: 876 kg ha^{-1} with 90 kg ha^{-1}, 749 kg ha^{-1} with 60 kg N ha^{-1}, 639 kg ha^{-1} at 30 kg N level while at 0 level, the yields were only to the extent of 441 kg ha^{-1}.
- ❖ The increase in castor bean yields over the 0 level was to the extent of 44.9 %, 69.8 % and 98.6 % at 30, 60 and 90 kg levels respectively.
- ❖ On an average, conventional tillage maintained higher grain yields of sorghum and castor to the tune of 30.4% and 57.0% respectively over minimum tillage. Among the residues, gliricidia application out performed the other two residues treatments in case of both the crops. Response of both the crops to graded levels of N application was tremendous. The highest yields of sorghum (1425 kg ha^{-1}) and castor (876 kg ha^{-1}) were recorded with application of 90 kg N ha^{-1}.

Influence on CO_2 emissions through soil respiration

- ❖ Monitoring of CO_2 fluxes emitted through soil respiration was undertaken after harvest of crop in this eleven year old (during 2005) experiment with sorghum-castor as crop rotation. CO_2 emission was significantly influenced by residues and N levels. However, significant effect of tillage was not seen on some of the Julian days. Irrespective of N levels and residues, in minimum tillage plots, relatively higher CO_2 emission (232.0 mg CO_2 m^{-2} hr^{-1}) was recorded compared to conventional tillage (216.0 mg CO_2 m^{-2} hr^{-1}). This may be attributed to higher microbial activity because of more biomass availability for microbial respiration. Moreover, the observations were recorded after 5 months of the tillage treatments (or sowing of crop) i.e. immediately after harvest of the crop. Presumably, by that time, the oxidative influence of conventional tillage might have come down because of compaction, etc.

Effect of management components on soil nitrogen pools

- ❖ The long-term influence of tillage, residues and N levels on various inorganic and organic N factions was studied under various treatments in sorghum-castor rotation. Among the inorganic fractions, exchangeable ammonical nitrogen varied from 17.1 to 42.1 mg kg^{-1} while the nitrate-N varied between 3.89 to 13.4 μg g^{-1} of soil across the management treatments.

- Significantly highest ammonical N was observed under conventional tillage (35.5 mg kg^{-1}) than under minimum tillage (26.8 mg kg^{-1}). Residue application significantly improved inorganic N fractions over 'no residue' application. Fertilizer N application significantly increased ammonical and nitrate N.
- Total hydrolyzable N varied from 333.6 to 648.9 mg kg^{-1} across the management treatments and residue application significantly increased total hydrolyzable N in soils. On an average, total hydrolyzable N was 508.5, 481.6 and 440.4 mg kg^{-1} under sorghum residues, gliricidia loppings and 'no residue' plots respectively. Fertilizer N also played an important role in improving the total hydrolyzable N pool and it was 577.2 mg kg^{-1} of soil @ 90 kg ha^{-1}.
- The order of contribution of different hydrolyzable fractions towards total hydrolyzable N was: amino acid N (51.5%) > unidentified N (21.4 %) > hydrolyzable ammonical N (13.01%) > hexosamine N fraction (8.41 %). Conspicuous influence of the application of residues and N levels on hexosamine N was observed while the influence of tillage and other interaction effects was not noticed. Tillage, residues as well as N levels significantly influenced the amino acid N fraction. On an average, significantly highest amino acid N content was observed under minimum tillage (265.0 mg kg^{-1}) followed by conventional tillage (225.7 mg kg^{-1}).
- Unidentified N fraction was significantly highest under conventional tillage (148.7 mg kg^{-1}) while under minimum tillage it was 110.2 mg kg^{-1}. Among the residues, on an average, the unidentified N fractions were significantly lower under application of gliricidia loppings (117.0 mg kg^{-1}) followed by 'no residue' application (127.5 mg kg^{-1}) while it was slightly higher under sorghum stover application (143.7 mg kg^{-1}).
- Fixed ammonical N, which represent the nitrogen retained in the clay lattices, varied between 97.8 to 183.8 mg kg^{-1} across the management treatments and was significantly influenced by tillage, residue application as well as varying N levels.

The present study has helped in creating a huge data base on the long and medium term influences of soil and nutrient management practices on soil quality indicators under diversity of soil and climatic condition in rainfed agroecology across the country which was earlier, lacking. Study has also helped in identifying the key indicators of soil quality for different soil types, climatic conditions and cropping system across the rainfed regions in the country which can be utilized further for improving soil quality. Another out come of this study is that it has helped in identifying best soil and nutrient management practices from the view point of improving soil quality and to improve crop yields on sustainable basis. At dryland centers soil quality assessment studies were undertaken in some of the farmer's fields also. Similarly, these studies were under taken for more than 300 farmers in Ranga Reddy district of Andhra Pradesh. Soil health reports were issued to these farmers for chemical quality parameters which would be useful for them in planning fertilizer applications. The concept and methodology adopted in this study is quite new and is comparable with that being followed at International level. The approach and findings of these studies will be highly useful to researchers, students farmers, NGO,s state agricultural departments, officers of soil testing laboratories in the country, land managers and policy planners. The outcome of the project will bring new dimensions in the land care and soil quality improvement program of the country. Studies conducted in Alfisol at Hyderabad have helped in identifying the best low cost INM treatments using farm based organics. Further, lot of valuable information has been generated through field experiments focusing on conservation agricultural practices on improvement of soil quality in Alfisol soils which are low in fertility, low in organic matter, having low clay content, poor in water retention and are susceptible to, crusting, hard setting and compaction. Despite our all efforts, there are few limitation and gaps in the study which will be removed in the second phase of the Fellowship.

5. Publications:

International

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National

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42. Ramakrishna, Y.S., Vittal, K.P.R., and Sharma, K.L. 2005. Conservation agriculture in rainfed semi-arid tropics-some past experiences, lessons learnt and future scope. *In:* Conservation Agriculture-Status and Prospects (eds: I.P. Abrol, R.K. Gupta., and R.K. Malik), Centre for Advancement of Sustainable Agriculture (CASA), PUSA campus, New Delhi. pp: 199-209.
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45. Sharma, K.L., Mandal, U.K., Vittal, K.P.R., Grace, J.K., Srinivas, K. and V. Ramesh (2006) Long term effects of agricultural water management practices on soil quality indicators in semi –arid tropical Alfisols. Abstract (Voluntary paper) in International Conference on Soil, Water and Environmental Quality- Issues and strategies, Indian Society of Soil Science, New Delhi.
46. Mandal, U.K., Sharma, K.L., Yadav, S.K. and V. Ramesh (2006) Estimation of active carbon for soil quality assessment under different land use systems of rainfed Alfisols. Abstract (Voluntary paper) in International Conference on Soil, Water and Environmental Quality- Issues and strategies, Indian Society of Soil Science, New Delhi.
47. Kausalya Ramachandran, Sharma, K.L., Srinivas, T., Sankar Rao, M., Gayathri, M and V. Bhaskar. 2006 Assessing agricultural sustainability in watersheds in India using Geomatics. Map Asia, Bangkok, Thailand, 29 August - 1 September 2006.
48. Sharma, K.L. 2007. Organic carbon build up- A challenge for organic farming in drylands. Lecture delivered in Winter School on "Organic Farming in Rainfed Areas" organized during 1-21st November 2007, by Central Research Institute for Dryland Agriculture, Saidabad, Santhoshnagar, Hyderabad-59.
49. Sharma, K.L. 2007. Strategies and approaches to assess and improve soil quality. Lecture delivered in a Model training course on "Soil and Moisture Conservation Techniques for Dryland Agriculture" sponsored by Directorate of Extension, Ministry of Agriculture, Govt of India, New Delhi during September 18-25, 2007; Organized by CRIDA, Hyderabad-59.
50. Sharma K.L. 2007. Attended a National workshop on "New Paradigm for rainfed farming-redesigning support systems and incentives" held at NASC campus, IARI, New Delhi during September 27-29, 2007.
51. Sharma, K.L. 2007. Participated in Workshop "Water management strategies for food security and environment quality" during 17-19 September, 2007, at Punjab Agricultural University, Ludhiana-141004, India.
52. Sharma, K. L. 2007. Invited to participate in the Workshop on " Soil health and customized fertilizers for Southern Region" at Hyderabad on Sept 03, 2007, organized by Fertilizer Association of India, Southern Region, Chennai- 32.
53. Sharma, K.L., Ramakrishna, Y. S., Korwar, G. R., Grace, J. K., Mandal, U.K., Srinivas, K., Sankar, G. R. M., Kausalya Ramachandran, Balloli, S. S., Madhavi, M., and Usha Rani, K. 2008. Effect of integrated use of fertilizers and farm-based organics on crop yields and soil

quality in rainfed Alfisols. Paper presented in National Seminar on "Integrated Nutrient Management in Rainfed Agro-ecosystems" held during 3-4th march, 2008 at CRIDA, Hyderabad.

54. Sharma K. L., Yadav, S. K., Pravin N. Gajbhiye, Uttam Kumar Mandal, Ramesh, V., Srinivas, K., Kusuma Grace J., and Madhavi, M. 2008. Effect of residue recycling on biological soil health indicators and surface CO_2 emissions in rainfed semi-arid tropical Alfisol under reduced tillage conditions. Paper presented in International Symposium on Agro-meteorology and Food Security held during 18-21st Feb, 2008 at CRIDA, Hyderabad.
55. Usha Rani, K., Sharma, K. L., Srinivas, K., Korwar, G.R., Nagasri, K., Sridevi Shankar K. and Venkanna, K. 2008 Assessment of sewage water quality under Musi river basin of Hyderabad in Andhra Pradesh. Paper presented in National Seminar on "Integrated Nutrient Management in Rainfed Agro-ecosystems" held during 3-4th march, 2008 at CRIDA, Hyderabad.
56. Kusuma Grace, J., Sharma, K. L., Srinivas, K., Mandal, U. K., Korwar, G. R., Balloli, S. S., Kausalya Ramachandran and Madhavi, M. 2008. Efficiency of Integrated Nutrient Management Treatments in Enhancing the Soil Quality under Sorghum-Castor System in Semiarid Tropical Alfisol. Paper presented in National Seminar on "Integrated Nutrient Management in Rainfed Agro-ecosystems" held during 3-4th march, 2008 at CRIDA, Hyderabad.
57. Sharma, K.L., Korwar, G. R., Srinivas, K., Mandal, U. K., Balloli, S. S., Kusuma Grace, J. and Venkateswarlu, B. 2009. Effect of conjunctive nutrient use practices and conservation tillage on crop yields and soil quality in rainfed Alfisol. Paper presented as poster in 4th World Congress on Conservation Agriculture for improving efficiency, equity and environment – Indian perspective, held during February 4-7, 2009, at New Delhi, India.
58. Sharma, K. L. 2009. Attended workshop on Potassium nutrition in Andhra Pradesh Agriculture organized by Conpotex- IPNI- Coromandel Fertilizers, Ltd., on 19 Jan, 2009.
59. Sharma, K. L. 2009. Attended 4th World Congress on Conservation Agriculture for improving efficiency, equity and environment – Indian perspective, held during February 4-7, 2009, at New Delhi, India.
60. Sharma, K. L. 2009. Attended 6th Global Knowledge Millennium Summit 2008 on Bio-Nano-The War on Hunger, New Delhi., organized by ASSOCHAM, during 13-14th February, 2009 at Hotel Shangri- La, New Delhi.
61. Venkateswarlu, B., Sharma, K.L., and Prasad, J.V. N. S. 2009. Conservation Agriculture- Constraints, issues and opportunities in rainfed areas. In: Lead papers, 4th World Congress on Conservation Agriculture, Innovations for improving efficiency, equity and environment. New Delhi, India. pp 80-84.

6. Seminar/ Symposium Attended:

S No	Particulars	Venue
1	Twentieth Biennial Workshop of All India coordinated Research project on Dryland Agriculture Oct 17 – 22, 2005	CRIDA, Hyderabad
2	93rd Indian Science Congress on Integrated Rural Development, Science and Technology. Jan 3-7, 2006	Rajendranagar, Hyderabad.
3	Participated in the meeting of Sub-group –III constituted for suggesting research and development priorities to Planning Commission on Natural Resources (Subgroup –III) held under the Chairmanship of Dr. P.S. Ramakrishna	J.N.U , New Delhi
4	Participated in the Working group meeting for identifying research priorities on rainfed agriculture held under the	CRIDA, Hyderabad

S No	Particulars	Venue
	Chairmanship of Dr J.C Katyal, Vice Chancellor, HAU.	
5	Participated in Research advisory committee meetings of the institute	CRIDA, Hyderabad
6	Participated in QRT interaction discussions in Labs and at FARM	CRIDA, Hyderabad
7	Participated in institute meetings to develop revised perspective plan vision 2025	CRIDA, Hyderabad
8	Participated in the interaction meeting on "Perspectives of second green revolution from rainfed areas" held with Dr MV Rao , former Additional DG , ICAR and Former VC , ANGRAU	CRIDA, Hyderabad
9	Participated in the meeting conducted for identifying NRM programs in farmers fields as per the suggestions of National Commission on agriculture	CRIDA, Hyderabad
10	International Symposium on Agro-meteorology and Food Security 18-21 February 2008	CRIDA, Hyderabad
11	Participated in Workshop "Water management strategies for food security and environment quality". 17-19 September, 2007	Punjab Agricultural University, Ludhiana-141004
12	Attended 4th World Congress on Conservation Agriculture for improving efficiency, equity and environment – Indian perspective, held during February 4-7, 2009	New Delhi, India
13	Attended workshop on Potassium nutrition in Andhra Pradesh Agriculture organized by Conpotex- IPNI-Coromandel Fertilizers, Ltd., on 19 Jan, 2009	Hyderabad
14	Attended 6th Global Knowledge Millennium Summit 2008 on Bio-Nano-The War on Hunger, New Delhi., organized by ASSOCHAM, during 13-14th February, 2009	Hotel Shangri- La, New Delhi.
15	Attended regional workshop on promotion of S fertilizer use in Indian Agriculture with reference to Andhra Pradesh organized by TSI-FAI on 20th Oct, 2008 at Hotel Taj Krishna, Banjara Hills, Hyderabad.	Hyderabad
16	Attended the 12th Working Group Meeting of AICRPDA, from 2-4 June, 2008 at OUAT, Bhubaneshwar and presented the strategic views on improving soil quality for breaking yield barriers in rainfed agriculture	OUAT, Bhubaneshwar

7. Courses taught:

Not applicable

8. Nature of lectures / Practicals taken / training lectures - NA

- Delivered various lectures as resource person during the trainings organized by the institute
- Worked as a resource faculty for summer and winter schools
- Guided PhD Students of ANGRAU and JNTU, Hyderabad.
- Worked as a organizing Secretary for National Seminar on INM during March 3-4, 2008.
- Various themes of training / lectures were as follows:

- Climate change and soil quality
- Integrated nutrient management
- Conservation agriculture and soil quality
- Residues recycling
- Land capability classification
- Nutrient management
- Soil testing and fertilizer management
- Importance of micronutrients in agriculture
- Watersheds

- Trained SMS, District Agricultural Officers, University lecturers/ associate professors, NGO's etc., from different states. Also organized training lectures to participants in collaboration with NIRD.

9. P.G. Students guided

Scientist acting as advisor	Student	Discipline	Institute/University
K.L.Sharma	Dr. J. Kusuma Grace	Environmental Sciences	JNTU, Hyderabad (PhD Completed)
K. L. Sharma	Dr. K. Usha Rani	Environmental Sciences	JNTU, Hyderabad (PhD. completed)
K. L. Sharma	Dr. Anantha Rao	Agronomy	ANGRAU, Hyderabad (Completed)

10. Honour/ Awards Received:

- **National / International level**

  - ICAR Junior fellowship holder during M.Sc programme (Selected on All India Competition basis)
  - Senior fellowship holder of IARI during Ph.D degree (Selected on All India Competition Basis)
  - Got selected for Commonwealth fellowship (UGC-Commonwealth) for the year 2003 in agriculture By UGC, New Delhi (But project was put under reserve category
  - Received ***Dhiru Morarji Memorial Award*** *(Shared first prize)* for the year 1990-91 for best article in Agricultural Sciences (received from FAI, New Delhi, India). The reference of the article is **Nutrient Balance and Sustainable Agriculture in Southern Plateau and Hills Region of India: Fertilizer News: 36 (6): 43-49**
  - Received ***Shriram Award (Shared first prize) for the year 1991-92*** for best article in Agricultural Sciences (received from FAI, New Delhi, India). The reference of the article is: **"Barani Phaslon mein poshak tatava prabandh ki bhumika, Khad Patrika ,1992 (August issue), 7-17.**
  - Received Dhiru ***Morarji Memorial Award (Shared 2nd prize)*** for the year 1998-1999 for best article in Agricultural Sciences (received from FAI, New Delhi, India). The reference of the article is: **Current status of Crop responses to fertilizers in rainfed areas- An experience from All India Coordinated Research Project for Dryland Agriculture 44: (5): 27-38.**
  - **Nominated as member of advisory board by the management of Green Farming – an International Journal Published from Jodhpur, India**

- **Institute/University/ State Level**

  Stood first in the Department of Soil Science and Water Management in HPKVV Palampur during M.Sc. degree.

- **Others (Specify):** Worked in the collaborative projects with ICRISAT, ACIAR, USDA, World Bank (NAARP, NATP)

11. Personal Recognition and other responsibilities/ activities

11 a) Peer Recognitions/ important invitations etc

1. Invited by Deccan Development Society, Hyderabad as ICAR nominee for conducting interviews for recruitment of staff for KVK, Zaheerabad

2. Acting as the editor for Journal of Indian Society of Soil Science, New Delhi. for 2007-08

3. Also acting as officiating Secretary and editor for Indian Society of Dryland Agricultural Research and Development, Hyderabad.

4. During the period under report Acted as reviewer for Geoderma, an International Journal.

5. Enrolled as member of Indian Nitrogen Group, a constituent body of the Society for Conservation of Nature, IARI, New Delhi

6. Acting as reviewer for the Current Science Journal

7. Also acting as reviewer for Indian Farming

8. Provided active support to the organizer of National seminar on integrated nutrient management sponsored by Ministry of Agriculture, held from 3-4 March, 2008 at CRIDA, Hyderabad.

9. Acted as chairman of the Technical Sessions Committee in the International Seminar on Agrometereology and Food Security held from 18-21 Feb., 2008 at CRIDA.

11 b) Other general and institutional activities:

1) Attending the national and international visitors who are coming to CRIDA and visiting the Central Laboratory
2) Carried out all other activities assigned by the Director of the Institute
   - Research labs. viz Soil Chemistry and Central laboratory were maintained for facilitating the research work to CRIDA scientist and others
   - Supervised the technical officers of the laboratory and provided technical guidance to them in various analytical works.
   - Time to time procured the equipments for the labs.
     - Acting as a member of Purchase Advisory Committee (PAC) of the Institute.
     - Acting as a member of committee for implementation of Official language in the

- Institute
- Acting as member of the Consultancy processing Cell of the Institute.
- Managing the National Fellow Unit, project and staff
- As and when required, looking after the duties of the Head DRM whenever the next senior is on tour or leave
- Worked in various technical committees constituted for the procurement of the various laboratory equipments
- Also worked as member in DPC committees of the Institute constituted for promotion of technical and administrative staff

- During the period under report, samples of soil, water, organic manures vermi-composts etc., received from farmers, business organizations and researchers, were analyzed on payment basis. This helped in generation of resources to the institute.
- Also handled AP Cess Fund Project with ICAR funding
- Also associated with NAIP project (world bank funded) on Soil Quality as Co-PI at Institute level

11 c) Member of the professional societies at present

a) Life member of Journal of Indian Society of Soil Science, New Delhi.

b) Life member of Indian Society of Dryland Agricultural Research and Development, Hyderabad

c) Life member for Indian Science Congress Association, Kolkota

d) Life member of Indian Society of Soil Survey and Land Use Planning, Nagpur

e) Life member of Association of Agro-meteorologists, Anand, Gujarat

f) Annual Member of Green Farming Journal, Jodhpur.

11 d) Activities related to transfer of technology

1. Technology related to INM ie conjunctive use of farm based low cost organic sources of N and inorganic sources of N have been developed. Some part of the technology is already in use in farmers field. This technology is being emphasized for application in farmer's field through various lectures, trainings, etc time to time

2. Acted as resource faculty to deliver lectures on soil and nutrient management/Conservation agriculture and soil quality, Soil Quality assessment under Tree based systems etc. during the training organized by TOT, winter schools etc.

3. Farmers, who approached directly to CRIDA headquarters for testing their soils, manures, etc., were provided need-based support.

4. Actively participated in Kisan Mela organized every year at Gunegal Farm of the institute. Also worked as chairman of the Resource Generation Committee constituted for organizing Kissan Mela

12. Details of budget allocation and expenditure statements up to 31-3-09

2005 – 2006 (From 4-2-05 to 31-3-06)

Head of A/c	Previous balance 4.2.05 to 31.3.05 (Rs)	Funds allocated for 2005-2006 (Rs)	Funds received from ICAR during 2005-2006 (Rs)	Expenditure during the year 2005-2006 (Rs)	Balance as on 1.4.2006 (Rs)
P&A	1,19,350	7,89,210	6,69,860	5,59,123	2,30,087
T.A	4,000	28,000	24,000	14,770	13230
Recurring Contingencies	20,000	1,50,000	1,30,000	1,55,576	-5576
NRC	Nil	19,60,000	19,60,000	11,13,100	8,46,900
Total (Rs)	1,43,350	29,27,210	27,83,860	18,42,569	10,84,641

(Note: Signed and authenticated copies are also enclosed)

2006 – 2007 (From 4.2.06 to 31-3-07)

Head of A/c	Previous balance 4.2.06 to 31.3.07 (Rs)	Funds allocated for 2006-2007(Rs)	Funds received from ICAR during 2006-2007(Rs)	Expenditure during the year 2006-2007 (Rs)	Balance as on 1.4.2007 (Rs)
P&A	Nil(old balance refunded back)	9,62,818	9,62,818	7,39,343	2,23,475
T.A	Nil	28,000	28,000	Nil	28,000
Recurring Contingencies	Nil	1,50,000	1,50,000	1,34,110	15,890
NRC	Nil	17,10,000	17,10,000	15,43,619	16,6,381
Total (Rs)	Nil	**28,50,818**	**28,50,818**	**24,17,072**	**4,33,746**

(Note: Signed and authenticated copies are also enclosed)

2007 – 2008 (From 01-04-07 to 31-3-08)

Head of A/c	Previous balance as on 1-4-2007 (Rs) (1)	Amount sanctioned for 2007-2008 (Rs) (2)	Amount released by the ICAR during 2007-2008 (Rs) (3)	Total amount available (Released + balance) during the financial year (4)=(1+3)	Expenditure during the year 2007-2008 (Rs) (5)	Balance as on 1-4-2008 (Rs) (6)=(4-5)
P & A	2,23,475	11,00,586*	7,44,485	9,67,960	9,30,842	37,118
T. A	28,000	28,000	0	28,000	6,880	21,120
Recurring Contingencies	15,890	1,50,000	1,34,110	1,50,000	98,916	51,084
NRC	1,66,381	3,50,000	1,83,619	3,50,000	1,34,313	2,15,687
Institutional Charges	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total (Rs)	**4,33,746**	**16,28,586**	**10,62,214**	**14,95,960**	**11,70,951**	**3,25,009**

(Note: Signed and authenticated copies are also enclosed)

2008 – 2009 (From 01-04-08 to 31-3-09)

Head of A/c	Previous balance as on 1-4-2008 (Rs) (1)	Amount sanctioned for 2008-2009 (Rs) (2)	Amount released by the ICAR during 2008-2009 (Rs) (3)	Total amount available (Released + balance) during the financial year (4)=(1+3)	Expenditure during the year 2008-2009 (Rs) (5)	Balance as on 1-4-2009 (Rs) (6)=(4-5)
P & A	325009	1317470/-	1170461/-	1317470/-	1237695/-	79775
Arrears paid to RA & SRF, Arrear paid to National Fellow on account of revision of pay (Including income tax deducted)		132625/-	132625/-	132625/-	136525/-	(-) 3900
i) @ 40% from 01-01-2006 to 30-8-08		0.000	0.000	0.000	207997	(-) 207997
ii) 01-9-09 to 28-2-09		0.000	0.000	0.000	160680	(-) 160680
T. A		28000		28000	0.00	28000
Recurring Contingencies		150000		150000	145534	4466
NRC		80000	80000	80000	36000	44000
Institutional Charges		Nil		Nil	0.00	0.00
Total (Rs)		**17,08,095**	**13,83,086**	**17,08,095**	**19,24,431**	**(-) 2,16,336**

(Note: Signed and authenticated copies are also enclosed)

13. Project Staff

S No	Name	Designation
1	Dr. K.L. Sharma	Principal Scientist & National Fellow (Soil Science)
2	Dr. J. Kusuma Grace	Research Associate
3	Ms. M. Madhavi	Senior Research Fellow
4	Mr. M. Surender Reddy	Junior Research Fellow
5	Ms. T. Kalpana	Stenographer

14. Suggestions for future lines of research

The concept of assessment and monitoring of soil quality systematically by incorporating the functional goals or management goals have not developed so far in India. The research efforts have been initiated during the recent years. Hence there is tremendous scope to strengthen the research components on this aspect. Some of the future lines of research are suggested as follows:

1. Identification or delineation of critical limits of dynamic physical, chemical and biological soil quality indicators to define degradation / limitation as very low, low, medium, high, very high (or) sufficient, adequate, toxic, (or) bad, good, better, best, (or) none, slight, moderate, severe, extreme depending upon the nature of the indicators. To achieve this, a very comprehensive database needs to be created through experimentation under different climatic, edaphic and management conditions.
2. More intensive studies are needed on the influence of soil management practices on advanced soil quality indicators and their related soil functions and soil processes.
3. Soil resilience vis-à-vis effective management practices need to be thoroughly explored to understand the efficacy of the management practices in improving soil resilience rate and time required to heal back / amend the soil to a desirable level for a sustained productivity.
4. Methodology of assessment of soil quality can be moderated by inclusion of predominant inherent indicators such as textural class, buffering capacity, morphological features like land slope, effective soil depth, etc. This aspect also needs systematic research efforts in future.
5. In order to extend the scope of soil quality indicators and indices in relation to environment, human health and economic returns on long-term basis, researchers need to consider produce quality, water quality, total returns, net returns, benefit cost ratio, as functional goals.

6. Once the key indicators are identified, research efforts need to be directed to develop and explore the fastest methodology of measuring these indicators rapidly in farmer's fields itself. It means researchers have to devote some time to develop rapid soil quality assessment kits for measuring predominant indicators periodically.
7. When the soil quality assessment studies are taken on a contiguous area, on catchments or watershed scale, it is essential that measured indicators be geo-referenced using GIS tools, so that information could be rapidly retrieved and viewed for managing the farms.
8. Research focus on translation of predominant indictors into soil health cards in simplest possible manner.
9. Research on extension modules involving latest state of the art information communication tools and media for creating awareness among the masses on soil health and land care, restoration of degraded soils and improvement of soil quality.

(Dr. K.L. Sharma)
Principal Scientist &
National Fellow (Soil Science)

(Dr. B. Venkateswarlu)
Director

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