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ICAR-CENTRAL RESEARCH INSTITUTE FOR DRYLAND AGRICULTURE
SANTOSHNAGAR, HYDERABAD-500059, T.S
Ph: 040-24530161 / 163, 24530157, Fax : 040-24531802

Efficient Soil Management Techniques for Minimizing Climate Change Impacts in Rainfed Areas February 2-9, 2016

CRIDA

Model Training Course on Efficient Soil Management Techniques for Minimizing Climate Change Impacts in Rainfed Areas

February 2-9, 2016

Compiled by
K.Ravi Shankar, S.S.Balloli,
K.Nagasree, G.Nirmala,
M.S.Prasad, R.Nagarjuna Kumar,
A.K.Indoria & Ch.Srinivasa Rao

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A Compendium of Lectures
DOE Sponsored Model Training Course on

सत्यमेव जयते
Government of India

EFFICIENT SOIL MANAGEMENT TECHNIQUES FOR MINIMIZING CLIMATE CHANGE IMPACTS IN RAINFED AREAS

Edited by

K. Ravi Shankar, S. S. Balloli, K. Nagasree, G. Nirmala, M. S. Prasad, R. Nagarjuna Kumar, A. K. Indoria and Ch. Srinivasa Rao

CENTRAL RESEARCH INSTITUTE FOR DRYLAND AGRICULTURE
(Indian Council of Agriculture Research)
Santoshnagar, Hyderabad – 500 059

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Course Director

M. S. Prasad,

S. S. Balloli,

K. Ravi Shankar

Co-Course Directors

K. Nagasree

A. K. Indoria

R. Nagarjuna Kumar

Editorial Assistance

S.L. Prasunamba

P. Kavitha

V. Madhavi

Technical Assistance

Surender Rao, K. (Photography)

Savithri, V.L.

Yadagiri, S.

Sataiah, K.

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The compendium of lectures has enlightened the Nutrient management strategies, Zero Tillage technologies, Conservation Agriculture, Soil Carbon sequestration strategies, Soil Health management, Integrated nutrient management and other related topics.

The feedback obtained from post- evaluation of relevant subject matter training programme has indicated a need for a ready reference in a compendium form which can impart latest technologies as well as information which can serve as documentary guide while working in the field conditions. This has motivated us to compile the diversified work which can serve the need of different stakeholders. We are highly thankful to the funding agency, Directorate of Extension, Ministry of Agriculture, GOI and also the line departments for deputing participants for the programme.

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On-Farm Generation of Organic Matter for Improved Soil Health, Crop Productivity and Drought Mitigation

Ch Srinivasa Rao
Central Research Institute for Dryland Agriculture, Santoshnagar, Saidabad Post, Hyderabad, 500 059, Andhra Pradesh
Email: director@crida.in

Declining per capita availability of natural resources due to population growth, urbanization, industrialization, competing environmental demands and all inclusive growth are major concerns of resource management and conservation. India has only 2.5% of the world's geographical area, but has about 17% of its population. India's population increased from 361 million in 1951 to 1140 million at present, a three-fold increase in a span of little over 50 years. By 2020, India needs about 300 million tones of food grains and the production in 2008-2009 was only 230 million tones, implying that about 70 million tones of food grains have to be produced from the same as lesser land, resulting in higher stress on soil system.

Rainfed area contributes almost 100% of minor and major forest products, 84-87% of coarse cereals and pulses, 80% of horticulture, 77% of oilseeds, 60% of cash crop of cotton, 50% of fine cereals etc. Rainfed regions support 60% of livestock, 40% of human population and contribute 40% to the food grains and several special attribute commodities of seed spices, dyes, herbs, gums etc. However, rainfed agro-ecologies are complex, diverse, fragile, risky, and under-invested and call upon regionally differentiated investments and management strategies (Srinivasarao et al., 2015). Government of India has launched a mega project with a budget of 350 crore rupees and CRIDA is leading this project for the last 2 years and this National Initiative for Climate Resilient Agriculture (NICRA) project is expected to be continued over next Five-Year Plan. Targeting 100 climate vulnerable districts of India, one of the major initiatives is to address the improvement of water and nutrient use efficiency as climate change adaptation and mitigation strategy

Water stress and low soil fertility are the key constraints of rainfed production systems of India. Therefore, interventions of water and soil fertility management should be carried out hand in hand. One of the most important factor for soil degradation and poor productivity of soil is low soil organic carbon. This also results in low water retention of added water or rain water. The soils of India are varied with diverse depth and water retention capacity. Charactrization of 21 locations in rainfed regions of India, showed the soil organic carbon content is low (Srinivasarao et al., 2009a).

Soils of arid and semi arid regions in India has diverse soil types covering Vertisols and vertic sub groups, Alfisols, Oxisols, Inceptisols, Aridisols, Entisols etc with rainfall variation between 400 mm to 1500 mm. Length of growing season is between 60-180 days mostly towards lower side. Besides the soils are highly degraded, low in soil organic carbon (Figure 1) and are multi-nutrient deficient (Table 3). Some of the regions of rainfed agriculture have extremely low soil organic carbon as low as 0.15 per cent. Most of the soils are deficient in N and P. Emergence of K, Mg, S besides Zn and B as major constraints of crop production in arid and semi arid regions of the country (Srinivasarao et al. 2006, 2008, 2009a,b, 2011a,b, 2012).

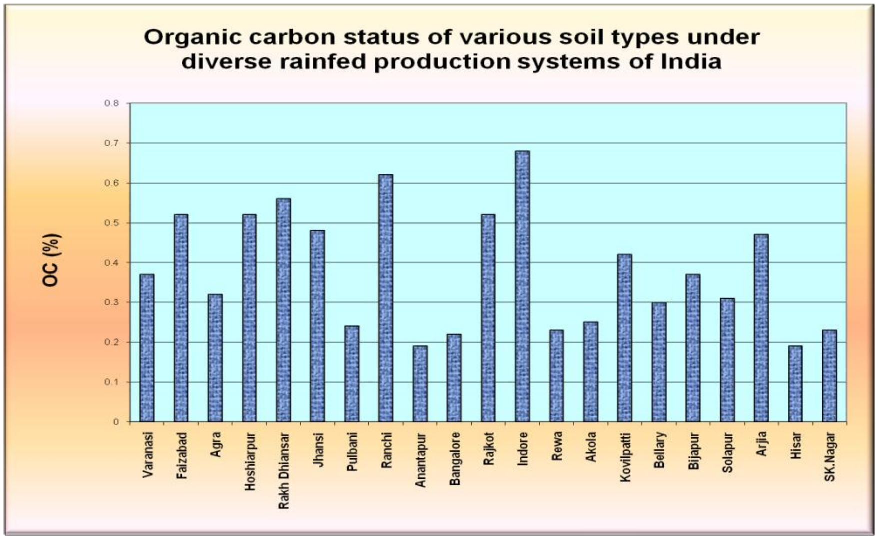


Figure 1. Rainfed regions in arid and semi arid tropical India are low in soil organic carbon (Srinivasarao et al., 2009a,b)

Table 2. Emerging Nutrient Deficiencies in Dryland Soils (0-15 cm) under diverse rainfed production system of India

Location	Rainfall (mm)	Soil type	Production System	Limiting Nutrients needs to supplied
Varanasi	1080	Inceptisol	Upland rice-lentil	N, Zn, B
Faizabad	1060	Inceptisol	Upland rice	N
Phulbani	1400	Oxisol	Upland rice-horsegram	N, Ca, Mg, Zn, B
Ranchi	1300	Alfisol	Upland rice	Mg, B
Rajkot	615	Vertisol	Groundnut	N, P, S, Zn, Fe, B
Anantapur	590	Alfisols	Groundnut	N, K, Mg, Zn, B
Indore	950	Vertisol	Soybean	-
Rewa	900	Vertic Inceptiol	Soybean	N, Zn
Akola	825	Vertisol	Cotton	N, P, S, Zn, B
Kovilpatti	750	Vertic Inceptisol	Cotton	N, P
Bellari	500	Vertisol	Rabi Sorghum	N, P, Zn, Fe
Bijapur	680	Vertisol	Rabi Sorghum	N, Zn, Fe
Jhansi	1020	Inceptisol	Kharif Sorghum	N
Solapur	720	Vertisol	Rabi Sorghum	N, P, Zn
Agra	665	Inceptisol	Pearl millet	N, K, Mg, Zn, B
Hisar	412	Inceptisol	Pearl millet	N, Mg, B
SK. Nagar	550	Aridisol	Pearl millet	N, K, S, Ca, Mg, Zn, B
Bangalore	925	Alfisol	Finger millet	N, K, Ca, Mg, Zn, B
Arjia	650	Vertisol	Maize	N, Mg, Zn, B
Ballowal-Saunkri	1000	Inceptisol	Maize	N, K, S, Mg, Zn
Rakh-Dhiansar	1200	Inceptisol	Maize	N, K, Ca, Mg, Zn, B

Source: Srinivasarao (2011)

Strategies to enhance soil organic carbon

Various management options are being promoted by Central Research Institute for Dryland Agriculture (CRIDA) in farmers participatory action research in several backward and tribal rainfed districts of India. Crop residue recycling, farm yard manure, biofertilizers, inclusion of legumes in the cropping sequence or as intercrops, green manure crops, green leaf manuring, tank silt addition, vermicomposting along with chemical fertilizers are some of the important options to improve soil health and crop productivity (Srinivasarao et al., 2011a,b). The most important technological options for on farm generation of organic matter to improve soil health, crop productivity and mitigation of droughts are given below

1) Crop residue recycling
2) Conservation agriculture
3) Green manuring
4) Composting (field crops, vegetable and fruit waste)
5) Silt recycling through tank silt
6) Pulses, Food legume and intercrops
7) Biochar (field crops, forest residue)
8) Cover crops and incorporation

Few of these options are given in detail below

Residue Management Recycling

For sustainable rainfed agriculture, the management of crop residues must from an integral part of the future tillage practices. There are several options available to farmers for the management of crop residues, including burning-the common practice, baling and removal, incorporation and surface retention. Burning, in addition to promoting loss of organic matter, nutrients and soil biota, also causes air pollution and associated ill effects on human and animal health. Baling is not practiced at the farmer level. Removal of crop residues is a loss of organic sources for soil health but is necessary to feed livestock and sustain mixed farming. Incorporation is a better option but it requires large amounts of energy and time; leads to temporary immobilization of nutrients, especially nitrogen; and the C: N ratio needs to be corrected by applying nitrogen at the time of incorporation.


Impact of surface residue retention on soil

Moderates soil temperature: Surface residue retention moderates soil temperature by avoiding soil temperature by avoiding direct exposure of soil to sunlight and/or acting by physical barrier to the heat loss from the soil as well as by increasing the dielectric constant due to moisture conservation. During summers, the maximum soil temperature remains lower and during winters the minimum temperature remains higher compared to bare soil which helps in avoiding adverse effect on crop.

Conserves soil moisture: The surface retained crop residues act as mulch which considerably reduces the evaporation losses from soil and helps in conserving soil and helps in conserving soil moisture. It is of immense importance in areas having scare water resources. In irrigated areas also, it will help in reducing the irrigation water requirement of the crop leading to less ground water mining which is responsible for falling water table in north-western plains.

The great role of stubble in protecting soil against both hydraulic and aeolian erosion is well known. Stubble mulching allied to minimum tillage is a well-established technique for protecting soil and conserving moisture in large-scale farming in cold semi-arid regions. Stover left on the field will also protect the soil, and cutting crops like maize and sorghum well above soil level can provide useful protection to the soil. In small-scale farm systems, however, straw and stover are often so greatly sought after as feed, thatch, bedding and fuel that crops are frequently cut to ground level, and maize roots may be dug out and dried as fuel.

Helps building up organic carbon: The slow decomposition compared to incorporation helps in building up the soil organic carbon. The soil organic carbon increased from 0.31 to almost 0.50 percent after your rice wheat crop cycles where the residue was either retained or incorporated. The build-up was higher in surface retained residues. In case of burning, there was marginal decrease in soil organic carbon.

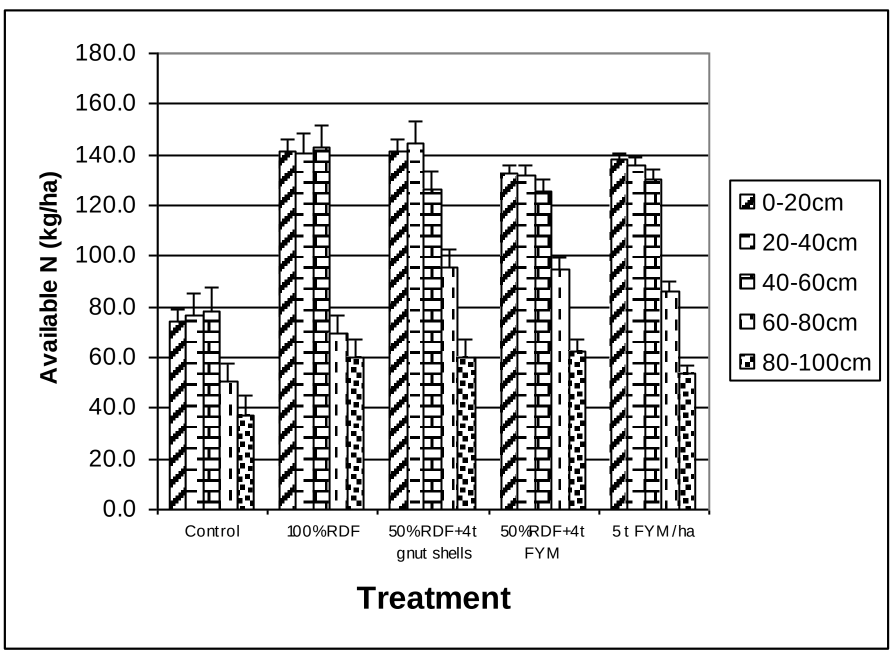
Reduces soil erosion: The surface retained residue absorbs the rain drop impact, helps in maintaining the soil structure whish leads to increased infiltration and reduced runoff. Moreover, it acts as a physical barrier for water runoff as well as direct effect of wind on soil.

R*educes nitrogen immobilization:* The surface retained crop residue due to limited contact with soil avoids short-term tying up of nutrients as is observed in incorporation. The top dressing of nitrogen in surface retained reduces must be done before irrigation to avoid interaction by the residues and the volatilization losses.

Source of nutrients: If properly managed, crop residues are excellent sources of nutrients besides improving soil physical, chemical and biological properties of soils. Nutrient status of different manures and crop residues indicated that pulse residues are rich source of all N, P, K and other essential plant nutrients. Use of non traditional crop residues like groundnut shells to groundnut crop improved soil available N substantially during 20 years of cropping on Alfisols of Anantapur (Andhra Pradesh) under arid conditions (Srinivasarao et al. 2009).

NPK content (kg/tonne) of some organic manures and crop residues

Manure / residue	N	P_2O_5	K_2O	Total
Manures				
Cattle / buffalo dung	5.0	2.0	5.0	12.0
Sheep / goat dung	6.5	5.0	3.0	11.8
Pig dung	6.0	5.0	4.0	15.0
Poultry manure	18.0	23.0	14.0	55.0
Farmyard manure	7.8	7.2	6.5	21.5
Biogas slurry	14.0	9.2	8.4	31.6
Vermi compost	18.0	20.0	8.0	46.0
Crop residues				
Rice	6.1	1.8	13.8	21.7
Wheat	4.8	1.6	11.8	18.2
Sorghum	5.2	2.3	13.4	20.9
Maize	5.2	1.8	13.5	20.5
Pearlmillet	4.5	1.6	11.4	17.5
Pulses	12.9	3.6	16.4	32.9
Oilseeds	8.0	2.1	9.3	19.4
Groundnut	16.0	2.3	13.7	32.0
Sugarcane	4.0	1.8	12.8	18.6



Impact of 20 years of groundnut shells and FYM additions on soil N improvement in red soils under arid conditions of Andhra Pradesh

Vermicomposting for improving soil health and crop productivity

Vermicomposting is the process of turning organic debris into worm castings. The worm castings are very important to the fertility of the soil. The castings contain high amounts of nitrogen, potassium, phosphorus, calcium, and magnesium. Castings contain: 5 times the available nitrogen, 7 times the available potash, and 1 ½ times more calcium than found in good topsoil. Several researchers have demonstrated that earthworm castings have excellent aeration, porosity, structure, drainage, and moisture-holding capacity. The content of the earthworm castings, along with the natural tillage by the worms burrowing action, enhances the permeability of water in the soil. Worm castings can hold close to nine times their weight in water. "Vermiconversion," or using earthworms to convert waste into soil additives, has been done on a relatively small scale for some time. A recommended rate of vermicompost application is 15-20 percent.

Vermicomposting is done on small and large scales. In the 1996 Summer Olympics in Sydney, Australia, the Australians used worms to take care of their tons and tons of waste. They then found that waste produced by the worms was could be very beneficial to their plants and soil. People in the U.S. have commercial vermicomposting facilities, where they raise worms and sell the castings that the worms produce. Then there are just people who own farms or even small gardens, and they may put earthworms into their compost heap, and then use that for fertilizer. Vermicompost is nothing but the excreta of earthworms, which is rich in humus and nutrients. We can rear earthworms artificially in a brick tank or near the stem / trunk of trees (especially horticultural trees). By feeding these earthworms with biomass and watching properly the food (bio-mass) of earthworms, we can produce the required quantities of vermicompost.

Sources of organic waste for manure production

The organic wastes that are available in agricultural areas include cattle dung, sheep dropping, biogas slurry, stubble from harvested crops, husks and corn shells, weeds, kitchen waste etc. All these materials can be used to produce vermicompost (Srinivasarao et al., 2011a,b).

Requirements

- **Housing:** Sheltered culturing of worms is recommended to protect the worms from excessive sunlight and rain. All the entrepreneurs have set up their units in vacant cowsheds, poultry sheds, basements and back yards.
- **Containers:** Cement tanks were constructed. These were separated in half by a dividing wall. Another set of tanks were also constructed for preliminary decomposition.
- **Bedding and feeding materials:** During the beginning of the enterprises, most women used cowdung in order to breed sufficient numbers of earthworms. Once they have large populations, they can start using all kinds of organic waste. Half of the entrepreneurs have now reached populations of 12,000 to 15,000 adult earthworms.

Process

The bedding and feeding materials are mixed, watered and allowed to ferment for about two to three weeks in the cement tanks. During this period the material is overturned 3 or 4 times to bring down the temperature and to assist in uniform decomposition. When the material becomes quite soft, it is transferred to the culture containers and worms ranging from a few days to a few weeks old are introduced into them.

A container of 1 metre by 1 metre by 0.3 metres, holds about 30-40 kgs of the bedding and feeding materials. In such a container, 1000 - 1500 worms are required for processing the materials. The material should have 40 to 50 percent moisture, a Ph of 6.3 to 7.5, and a temperature range of 20 to 30 degree celsius. The earthworms live in the deeper layers of the material. They actively feed and deposit granular castings on the surface of the material. The worms should be allowed to feed on the material until it is converted into a highly granular mass. The earthworms take 7 weeks to reach adulthood. From the 8th week onwards they deposit cocoons. One mature worm can produce two cocoons per week. Each cocoon produces 3-7 young after an incubation period of 5-10 days depending on the species of worms, quality of feed, and general conditions. The resulting increase is about 1200-1500 worms per year. The population doubles in about a months time.

Harvesting of Vermicompost

The harvesting of vermicompost involves the manual separation of worms from the castings. For this purpose, the contents of the containers are dumped on the ground in the form of a mound and allowed to stand for a few hours. Most of the worms move to the bottom of the mound to avoid light. The worms collect at the bottom in the form of a ball. At this stage, the vermicompost is removed to get the worms. The worms are collected for new culture beds. The vermicompost collected is dried, passed through a 3 mm sieve to recover the cocoons, young worms, and unconsumed organic material. The cocoons and young worms are used for seeding the new culture beds. The vermicompost recovered is rich in macro-nutrients, microbes such as *actinomycetes* and nitrogen fixers, and is used as a manure.

Benefits

By establishing vermiculture units entrepreneurs can recycle their own resources and create an effective fertiliser in the process. The extra worms that are produced can be used as feed for poultry and fish. The advantages of this technology include (Srinivasarao et al., 2011a,b):

1. Recycling of organic wastes.
2. Production of energy rich resources.
3. Reduction of environmental pollution.
4. Provision of job opportunities for women and jobless people.
5. Improvement of soil pH. (vermicompost acts as a buffering agent).
6. Improvement in the percolation property of clay soils (from the compost's granular nature).
7. Improvement of the water holding capacity in sandy soils.
8. Release of exchangeable and available forms of nutrients.
9. Increase of oxidizable carbon levels, improving the base exchange capacity of the soil.
10. Improvement of the nitrate and phosphate levels.
11. Encouragement of plant root system growth.
12. Improvement in the size and girth of plant stems.
13. Early and profuse plant flowering
14. Creation of a substitute protein in poultry and fish feed.

***Gliricidia* green leaf manuring: On-farm generation of organic matter**

Green leaf manuring of Gliricidia sepium is the most promising and climate friendly technology. Green leaf manure plants such as *Gliricidia* can play an important role in tropical farming systems for increasing the soil fertility. Commonly known as Kakawate, used as insecticide, repellant and rodenticide, can thrive in dry moist, acidic soils or even poor degraded, infertile soils under rain fed conditions. Green leaf manuring is one of the important farming practices for increasing organic matter content in the soil. In highly degraded soils, especially in the tropics, soils lack sufficient amount of nitrogen (N). Green leaf manure plants such as Gliricidia can play an important role in tropical farming systems for increasing the soil fertility. Growing Gliricidia plants on farm bunds serves dual purpose of producing green leaf manure rich in N, under field conditions and also helps in conserving soil through reduced soil erosion.

Gliricidia sepium (Jacq.) Steud. (syn. Gliricidia maculate H.B.K.) is a fast growing, tropical, leguminous tree. It is one of the commonest and bewt-known multipurpose trees in many parts of Central America, Mexico, West Africa, West Indies, South Asia, and tropical Americas. The tree is used for timber, firewood, hedges, medicinal purpose, charcoal, live fences, plantation shade, poles, soil stabilization, and as green manure. The toxic property of the seeds and bark has given rise to the generic epithet (gliricidia = mouse killer). Gliricidia sepium adapts very well in a wide range of soils ranging from eroded acidic (pH 4.5-6.2) soils, fertile sandy soils, heavy clay, calcareous limestone and alkaline soils. Gliricidia tolerates fire and the trees quickly re-sprout with the onset of rains.

Gliricidia sepium, is a fast-growing, tropical, leguminous tree commonly known as gliricidia, mata raton (spanish), cacao de nance, cacahnanance, madriado (honduras), kakawate (philippines), madre cacao (guatemala). It is one of the commonest and a best-known multipurpose tree probably originated from Central America, but has also spread to West Africa, the West Indies, Southern Asia and the tropical Americas. It is used as a live fencing in many tropical and sub-tropical countries. There are considered to be only four species (Polhill and Sousa 1981), of which *G. sepium* (common name 'gliricidia') is the only species of real agronomic potential.

Glyricidia seedlings

Characteristics of Gliricidia

- *Gliricidia is a woody, green leaf manure tree about 12 m in height.*
- *The foliage can be used as green manure (natural fertilizer).*
- *Gliricidia is a root nodulating, N-fixing, and multipurpose legume.*
- *It grows fast and is tolerant to pruning.*
- *It can thrive in dry, moist, acidic soils or even poor degraded, infertile soils under rainfed conditions.*
- *The leaves contain nutrients: N (2.4%), phosphorus (P) (0.1%), potassium (K) (1.8%), calcium (Ca), and magnesium (Mg).*
- *Gliricidia* adds plants nutrients and organic matter to the soil and increases crop productivity on infertile and degraded soils.

Cultivation and Management Practices

Propagation

Gliricidia can be propagated through stem cuttings or seed.

Stem cutting or stake method

Gliricidia cuttings are taken from stems of at least one-year-old plants. These should be from brownish-green mature branches and should measure 2-6 cm in diameter and 30-100 cm in length. The stem cutting is normally cut obliquely at both ends, discarding the younger tips and the base is inserted 20-50 cm into the soil. The cuttings should be planted on bunds in the rainy season immediately after these are cut from the stems. The plants grow quickly from cuttings. Propagation from stakes is simple but suitable mainly for situations where only a few trees are to be established. For hedges, cuttings are planted closely at 50 cm spacing. The hedges can be periodically pruned to provide fodder, green manure, firewood, or stakes for new fences.

Seed propagation

Gliricidia seeds are soaked in water for 8-10 h, preferably overnight. The soaked sees are sown in small polythene bags filled with a mixture of red soil, sand, and farmyard manure (1:1:1) and watered regularly. Generally, 3- to 4-month-old seedlings can be planted on bunds in the rainy season. Seed propagation method is more convenient for establishing a large number of plants.

Benefits of Gliricidia

Role in soil management (Srinivasarao et al., 2011a,b).

- Increases organic matter content in the soil.
- Improves soil physical properties.
- Restores and improves the soil fertility.
- Increases crop yields.
- Allows the water to infiltrate into the soil more quickly rather than run off the surface.
- Increases water-holding capacity of the soil.
- Reduces soil erosion.
- Increases nutrient availability in the soil due to production of carbon dioxide and organic acids during decomposition of the plant material.
- Adds valuable nutrients such as N, P, K, Ca, and Mg to the soil. *Gliricidia* plants grown on 700-m long bunds can provide about 30 kg N $ha^{-1}yr^{-1}$ under rainfed systems with 700-800 mm annual rainfall.
- Reduces environmental risks associated with chemical fertilizers (Srinivasarao et al., 2011a,b). Use of *Gliricidia* as green manure minimizes the usage of chemical fertilizers that are very expensive and also environmentally unfriendly.

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Climate Change and its impact on Dryland Agriculture in India

V U M Rao, Project Coordinator (Agromet)
All India Coordinated Project for Agrometeorology
CRIDA, Hyderabad 500059
Vumrao54@gmail.com

Introduction

Indian agriculture continues to be backbone of Indian economy by providing employment to more than 60 per cent of the population and is the prime arbiter of living standards for 70 per cent population that live in the rural areas. Its contribution to gross domestic product (GDP) has declined from 57 per cent in 1950–51 to around 17 per cent (2011–2012) due primarily to growth in other sectors of the economy. However, the declining share of the agricultural sector has not affected the importance of the sector in the Indian economy.

About 55 per cent of the total cropped area is still rainfed and dependent on the uncertainties of the monsoon which indicates the close relationship between Indian agriculture and climate. Therefore the change in climate has become an important area of concern for India to ensure food and nutritional security for a growing population. Several global studies have indicated that the impacts of climate change are global, but countries like India are more vulnerable in view of the high agriculture dependent population. The warming trend in India over the past 100 years has indicated an increase of 0.56 ºC. Negative impacts of these changes on yield of wheat and paddy in parts of India due to increased temperature, increased water stress and reduction in number of rainy days are already felt. Significant negative impacts have been projected with medium-term (2010-2039) climate change, eg. yield reduction by 4.5 to 9 per cent, depending on the magnitude and distribution of warming, eroding roughly 1.5 per cent of the GDP per year.

Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. According to Inter-governmental Panel on Climate Change (IPCC), it refers to a change in the state of the climate that can be identified (e.g. using statistical tools) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Increasing evidence over the past few decades indicates that significant changes in climate are taking place worldwide as a result of enhanced human activities. The inventions that revolutionized the way we live during last few centuries, more so in the last century had altered the concentration of atmospheric constituents that lead to global warming. The major cause of climate change (global warming) has been ascribed to the increased levels of greenhouse gases like carbon dioxide (CO2), methane (CH4), nitrous oxides (NO2), chlorofluorocarbons (CFCs) beyond their natural levels due to the uncontrolled activities such as burning of fossil fuels, increased use of refrigerants, and enhanced agricultural related practices.

Lack of food security poses a particular burden on people and nations in the dryland regions of the world, particularly in tropical areas of Africa and Asia that are experiencing rapid population growth and/or high population density. Global food demand is expected to be more than double by 2050 because of population growth and increased per capita consumption. While the challenge cannot be met through increased agricultural production alone, increased production is essential as part of the solution. However, in many cases including India, production capacities of dryland countries are deteriorating in the face of rapid population growth, misdirected agricultural practices, and widespread of land degradation (Rao, et al., 2007). The environmental conditions of the world's/India's drylands and unpredictability of rainfall make these areas marginal for intensive agriculture. Land degradation in drylands due to water erosion, loss of soil fertility, ground water depletion and loss of vegetation, results in the decline of both economic and environmental potential in these regions.

About 15 million ha of dryland lies in the arid region which receives < 500 mm rainfall; another 15 million ha is in 500-750 mm rainfall zone, 42 million ha is in 750-1150 mm rainfall zone, with the remaining 25 million ha receiving > 1150 m rainfall per annum (Kanwar, 1999). About 74 % of annual rainfall occurred during June-September, the southwest monsoon. This monsoon is characterized as having a high coefficient of variation (0.3-0.6) with July and August as the rainiest months. Droughts occur once in 3 to 5 years either due to a deficit in seasonal rainfall during the main cropping season or from inadequate soil moisture availability during prolonged dry spells between successive rainfall events (Ramakrishna *et* al., 1999).

In India, low yields and crop failures in these drylands often lead to food and fodder scarcity resulting in a near–famine situation that further accelerate the process of land degradation. Alfisols, Entisols, Vertisols and associated soils dominate the SAT areas (Virmani, *et al*., 1991). These soils are generally highly degraded with low water retentive capacity, and have multiple nutrient deficiencies. In the dryland's of Indian human population is likely to reach 600 millions by 2025 from the present 410 millions. Similarly, the livestock population is likely to exceed 650 million by 2025 from the present 509 million. On the other hand, the area under dryland crop production may decrease to 85 million ha by 2025 from the present 97 million ha. Thus, from such a significantly reduced cultivated area, crop production must increase from the present 0.8 to 1.0 t ha^{-1} to 2.0 t ha^{-1} by 2025.

Production and productivity trends

An average food grain yield of 2 t ha^{-1} will be required from drylands (and about 4 t ha^{-1} from irrigated agriculture) to feed the projected population of 1500 million by 2025 AD from the prevailing productivity level of <1.0 t ha^{-1}. More than the calories, ensuring protein security will become an important issue in view of the predominantly vegetarian habits of Indians and dwindling availability of vegetable proteins (pulses; current supply of pulses is about 25 g $head^{-1}$ day^{-1} against the minimum dietary need for about 70 g $head^{-1}$ day^{-1}) There has been a slow down in production growth in major rainfed crops from mid 1990s, particularly, in coarse cereals, oilseeds and pulses. This is attributed mainly to falling trend in area and stagnant productivity. Projections for 2025 indicate further fall in area and production, unless, substantial gains in productivity and profitability are realized. The yield growth in pulses is of particular concern. The lower production of pulses as already reflected in sharp rise in prices during the last two years. However, considering the yield gaps between research stations, on-farm trials and farmers' fields, it is still possible to enhance the yield levels with appropriate policy, timely inputs supply, credit and extension support. On overall basis, attaining a goal of 2 tonnes of food grains ha^{-1} may not be beyond reach in the semi-arid lands with a mean annual rainfall of 750 mm (CRIDA, 2007).

Establishment of Dryland Project

The Green Revolution in mid 1960s, though a boon to Indian agriculture, ushered in an era of alarming disparity between productivity of irrigated and rainfed agriculture. Concentration was on enhanced production of a few commodities like rice and wheat, which could quickly contribute to increased total food and agricultural production. This resulted in considerable depletion of natural resources and the rainfed dry areas (low productive areas) having high concentration of malnourished people are deplorably aggravating problems of inequity and regional imbalances. This era also witnessed associated risks such as, rapid loss of soil nutrients, agro-biodiversity including indigenous land races and breeds. These socio-economic imbalances led to a serious rethinking on inducting an in-depth research programme to stabilise the performance of the then introduced hybrids of sorghum and pearl millet in rainfed regions and to moderate the periodic drought related adverse impact on their productivity. The consecutive droughts of 1965 and 1966 catalysed further the process of vigorous efforts in dryland research. At that juncture, the Indian Council of Agricultural Research (ICAR) rose to the occasion and formulated a comprehensive programme on dryland research. In 1970, an All India Coordinated Research Project for Dryland Agriculture (AICRPDA) was launched by the ICAR. The unique feature of this project, compared to earlier programmes was its reliance on a multi-disciplinary approach in identifying and analysing the constraints in the production of rainfed agriculture limiting crop yields in vast areas of semiarid and seasonally dry areas of the country. Since no two-dryland locations face identical problems of uncertainty of weather and diversity of soils, AICRPDA functioned across 23 Cooperating Centres (currently 22 centres exist) representing contrasting agroclimatic regions of the country. The project activities increasingly established all the possibilities to accrue at least double the dryland crop productivity by employing soil and water conservation practices, improved varieties, good sowing methods, weed control and fertilizer use. The modest beginning of AICRPDA resulted in the establishment of a full-fledged research organization - the Central Research Institute for Dryland Agriculture (CRIDA) at Hyderabad in 1985 (CRIDA, 2007). With an aim to bring stability in food grain production in the face of varying weather conditions, Government of India recognized the importance of Agrometeorology and started strengthening it at its various Research Institutes functioning under ICAR. The National Commission on Agriculture (NCA) (1976) strongly recommended for establishment of Departments of Agricultural Meteorology at each State Agricultural University of strengthening teaching and research in Agricultural Meteorology. The inception of All India Coordinated Research Project on Agrometeorology (AICRPAM) during 1983 at CRIDA, Hyderabad was the culmination of the prompt response of ICAR to the recommendations of NCA.

The Project maintains its uniqueness among other network projects by not confining to a single commodity or crop and a particular ecosystem or climatic condition. The research domain of the project cuts across all the four agro ecosystems, viz., Rainfed, Irrigated, Hill & Mountain and Coastal Island. Unlike other Network Project on Agrometeorology elsewhere in the world, which are mostly focused on data collection and operational research, it is engaged in both basic and operational research. Each centre conducts Agrometeorological research on one or two main crops of its region besides analyzing long-term weather data for Agroclimatic Characterization and Climate Change Studies. Bi-weekly Agro Advisory Services (AAS) using the research results obtained over the years are disseminated through its website. The Cooperating Centres are also conducting awareness programs on climate change related issues among the farming community through special programs. The project is being operated with 25 centers across country covering almost all agroclimatological zones of India.

Climate Change and Indian Agriculture Impact, Adaptation and Vulnerability

Climate change is increasingly seen as the major threat to the food security and sustainability of agriculture in India. Keeping in view of the importance of this problem, Indian Council of Agricultural Research initiated a National Network project on "Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change (NPCC). The nation-wide network project first of its kind in ICAR, was started in 2004 during the X Plan with 15 Institutes which was increased to 23 in XI Plan (2007-12). These institutes/universities covered all major sectors of agriculture viz., crops, horticulture, plantations, live-stock, inland and marine fisheries, poultry and natural resources like water and soil. Since 2013 this project was merged with new mega project namely "National Initiative on Climate Resilient Agriculture (NICRA)".

In India, significant negative impacts have been implied with medium-term (2010-2039) climate change, predicted to reduce yields by 4.5 to 9 percent, depending on the magnitude and distribution of warming. Since agriculture makes up roughly 16 per cent of India's GDP, a 4.5 to 9% negative impact on production implies a cost of climate change to be roughly up to 1.5 percent of GDP per year. The Government of India has accorded high priority on research and development to cope with climate change in agriculture sector. The Prime Minister's National Action Plan on climate change has identified Agriculture as one of the eight national missions.

With this background, the ICAR has launched a major Project entitled, **National Initiative on Climate Resilient Agriculture (NICRA)** during 2010-11 with an outlay of Rs.350 crores for the XI Plan with the following objectives.

- To enhance the resilience of Indian agriculture covering crops, livestock and fisheries to climatic variability and climate change through development and application of improved production and risk management technologies.
- To demonstrate site specific technology packages on farmer's fields for adapting to current climate risks
- To enhance the capacity building of scientists and other stakeholders in climate resilient agricultural research and its application.

Both short term and long terms outputs are expected from the project in terms of new and improved varieties of corps, livestock breeds, management practices that help in adaptation and mitigation and inputs for policy making to mainstream climate resilient agriculture in the developmental planning. The overall expected outcome is enhanced resilience of agricultural production to climate variability in vulnerable regions. The project is comprised of four components.

1. Strategic research on adaptation and mitigation
2. Technology demonstration on farmer's fields to cope with current climate variability
3. Sponsored and competitive research grants to fill critical research gaps
4. Capacity building of different stake holders

   The NICRA project will continue in future also

Impact of Climate Change

It is difficult to visualize the specific impact of climate change on dryland agriculture by 2025, but some signs are emerging which indicate that rainfed areas are likely to witness more weather extremities like droughts, floods and cold waves as compared to the past. As per the predictions made using General Circulation Model (GCM), the temperatures are likely to increase from 1.0 to 2.0^{o}C by 2025 AD and consequently, there may be shifts in the rainfall and its temporal and spatial distribution. Increase in green house gas emissions also will have an impact on agriculture and water resources. There appear to be both positive and negative effects of elevated CO_2. With increased pressure on the limited cultivated area, a faster depletion of nutrients and groundwater appear to be a definite possibility (CRIDA, 2007). The extreme events like the quantum of daily rainfall as well as intensity have increased causing more erosive rains. The effects of climate change can be mitigated through proper rainwater management, crop planning, alternate crops/cropping systems, integrated farming systems, enhancement of water productivity, precision farming, knowledge transfer (agro-advisories) etc. The specific interventions are:

- Agronomic manipulation
- Evolving crop varieties to withstand warming
- Varieties to face possible newer pest-disease complexes
- Crops and varieties that fit into new cropping systems and seasons
- With skewed & high rainfall, the specifications of water harvesting structures need specific attention in wet semiarid & humid regions.

The following crop-based approaches may be followed for coping with the climate change.

- Crops and varieties that fit into new cropping systems and seasons
- Development of varieties with changed duration
- Varieties for high temperature, drought, inland salinity and submergence tolerance
- Livestock health and productivity
- Varieties which respond to higher level of carbon dioxide
- Varieties with high fertilizer and radiation use efficiency

Under national action plan for climate change the activities under sub-mission “Dryland Agriculture” include:

- Development of drought, temperature and pest resistant crop varieties Maximize infiltration of rainwater
- Improved methods of soil and water conservation that help crops to adapt extreme weather conditions
- Stakeholders consultation and awareness generation on climate change and sharing and dissemination of information
- Devise financial support mechanisms to enable farmers invest in risk mitigation

Dryland Development Avenues – R&D Challenges

With the changing climate change and economy the development of dryland areas are gaining much importance and the issues are becoming complex to solve. However some of the important areas needing attention of the research and development units are as follows.

- Yield gap analysis (Sustainable yield index respecting the environment, SWOT analysis, crop substitution, selective mechanisation)
- Trade-off between blue and green water (Water harvesting, water productivity, ground wate recharge, crop and agronomy etc.)
- Climate change- ready technology (Coping with extreme events, GHGs emissions, carbon sequestration and trading, crop models, weather forecast, biotechnology, National Action Plan for climate change, micro level characterization, space technology etc.)
- Convergence of the programs on rainfed area development (NRAA, NREGS, Watershed program, NHM etc.)
- NRM based robust loan and crop insurance program (Win-win situation for the company and farmer)
- Use of ICT (Net planning, DSS, crop and environmental modeling, drought management Plan,contingency planning etc.)
- Participatory planning, monitoring and conflict resolution (Self governance, awareness, capacity building, gender issue, ITKs to MTKs, action learning research etc.)
- Post harvest value addition (Rural entrepreneurship, small- scale cottage industry, employment generation etc.)

The final challenge lies on combining the output of resource balance (water balance, energy balance, carbon balance, nutrient balance and economic balance) in a single sustainability parameter to evaluate the dryland technology.

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Climate Change Impacts on Soil Health

Balloli, S.S. and Ch. Srinivasa Rao

Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad- 500 0059, email: ssb@crida.in

Climate Change Predictions

Climate models suggest (IPCC, 2007) an increase in global average annual precipitation during the 21st century, although changes in precipitation will vary from region to region. Tropical and high-latitude regions are expected to receive high intensity rainfall. Annual average precipitation increases over most of northern Europe, the Arctic, Canada, the northeastern United States, tropical and eastern Africa, the northern Pacific and Antarctica, as well as northern Asia and the Tibetan Plateau in winter. Annual average precipitation decreases in most of the Mediterranean, northern Africa, northern Sahara, Central America, the American Southwest, the southern Andes, as well as southwestern Australia during winter.

Carbon dioxide concentrations in the atmosphere will increase throughout the 21st century according to all IPCC scenarios. The scenarios project CO_2 concentrations ranging from 535 to 983 parts per million (ppm) by 2100, which is 41 to 158 percent higher than current levels (IPCC, 2007). The average surface temperature of the Earth is likely to increase by 2 to 11.5°F (1.1-6.4°C) by the end of the 21st century, relative to 1980-1990, with a best estimate of 3.2 to 7.2°F (1.8-4.0°C). The average rate of warming over each inhabited continent is very likely to be at least twice as large as that experienced during the 20th century (IPCC, 2007).

One current opinion is that the decomposition of soil labile carbon is sensitive to temperature variation whereas resistant components are insensitive. The resistant carbon or organic matter in mineral soil is then assumed to be unresponsive to global warming. But the global pattern and magnitude of the predicted future soil carbon stock will mainly rely on the temperature sensitivity of these resistant carbon pools. To investigate this sensitivity, Fang et al (2004) based on incubation studies have reported that SOM decomposition or soil basal respiration rate was significantly affected by changes in SOM components associated with soil depth, sampling method and incubation and, that the temperature sensitivity for SOM decomposition was not affected, suggesting that the temperature sensitivity for resistant organic matter pools does not differ significantly from that of labile pools, and that both types of SOM will therefore respond similarly to global warming.

Why climate change impacts alter soil health?

Soil fertility in simple terms is the ability of the soil to provide nutrients in appropriate form and in right quantity to the plants. Soil physical, chemical and biological properties and some of the processes like weathering, mineralization, immobilization, nitrification, denitrification, biological nitrogen fixation, root-microbe interaction and nutrient movement influence soil fertility. All these soil properties and processes that influence the availability of nutrients to plant growth depend on rainfall, temperature, soil carbon dioxide content, amount of soil moisture in the soil, agricultural drought, relative humidity, etc (Table 1). As per the predictions of IPCC 2007, rainfall, temperature, carbon dioxide are going to vary considerably in the coming years. Hence, for increasing and sustaining the agricultural production it will be very apt to understand the impacts of these parameters on soil fertility and carbon sequestration. This paper explores how rising temperature, drought and more intense precipitation events projected in climate change scenarios for the 21st century might affect soil fertility and the mineral nutrition of crops and carbon sequestration.

Table. 1. Potential interactions of global change variables with mineral stress

Process	Global Change variable	Interaction with the mineral stress
Erosion	heavy precipitation; Drought	general losses of soil nutrients, SOC and fertilizer
Transpiration-driven mass flow	drought, temperature, RH,	CO_2, NO_3, SO_4, Ca, Mg, and Si
Root growth and architecture	drought, soil temperature	CO_2 All nutrients, especially P and K
Mycorrhizas (ectomycorrhizas)	CO_2	P, Zn (VAM) N
Biological N Fixation	drought	soil temperature N
Soil microbes (N cycling)	drought	soil temperature N
Soil leaching	heavy precipitation	NO_3, SO_4, Ca, Mg
Soil redox status	flooding	Mn, Fe, Al and B
Soil organic carbon status soil moisture, soil temperature		CO_2,all nutrients
Plant phenology	temperature	P, N, K
Salinization	precipitation, temperature	Na, K, Ca, Mg

Impact of drought on nutrient availability

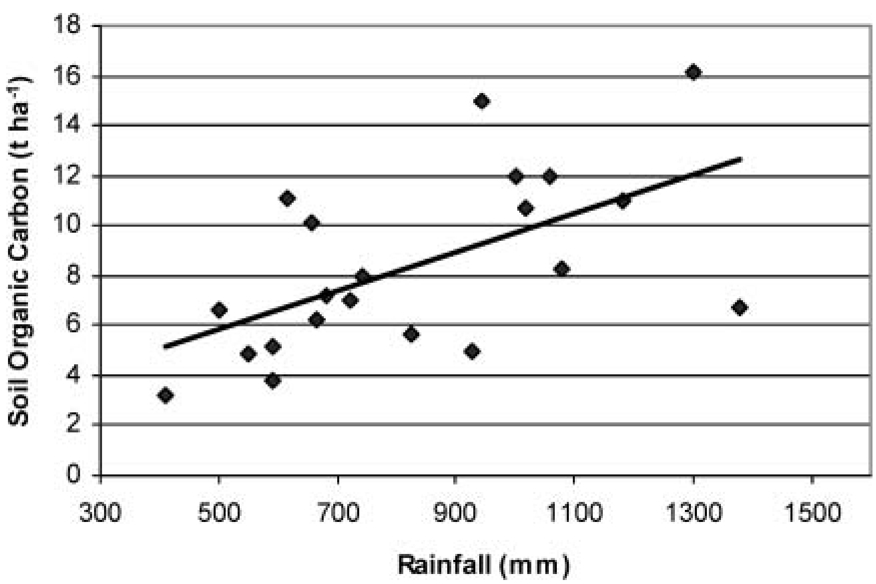
Agricultural drought i.e. soil moisture deficit directly impacts crop productivity but also reduces yields through its influence on the availability and transport of soil nutrients. Drought increases vulnerability to nutrient losses from the rooting zone through erosion (Gupta 1993). Because nutrients are carried to the roots by water, soil moisture deficit decreases nutrient diffusion over short distances and the mass flow of water-soluble nutrients such as nitrate, sulfate, Ca, Mg, and Si over longer distances (Mackay and Barber 1985; Barber 1995). Reduction of root growth and impairment of root function under drought conditions thus reduces the nutrient acquisition capacity of root systems (Marchner 1995). Drought also disrupts root-microbe associations that are a principal strategy for nutrient capture by plants. Reductions in both carbon and oxygen fluxes and nitrogen accumulation in root nodules under drought conditions inhibit nitrogen fixation in legume crops (Athar and Ashraf 2009). Drought alters the composition and activity of soil microbial communities which determine the C and N transformations that underlie soil fertility and nutrient cycling (Schimel et al. 2007). For example, soil moisture deficit has been shown to reduce the activity of nitrifying bacteria by slowing diffusion of substrate supply and through cytoplasmic dehydration (Stark and Firestone 1995). Studies suggest that the root-mycorrhizal symbiosis is not overly sensitive to moderate soil moisture deficits (Garcia et al. 2008). There is a large literature documenting the beneficial effects of mycorrhizal fungi in crops plants experiencing drought conditions (Wu and Chang 2004; Boomsma and Vyn 2008). Part of the benefit provided by mycorrhizae under drought conditions is associated with increase in nutrient transfer to the roots (Goicoechea et al. 1997; Al-Karaki and Clark 1998).

Impacts of heavy rainfall on nutrient availability

Intense rainfall events can be a major cause of erosion in sloped cropping systems and where soil instability results from farming practices that have degraded soil structure and integrity. Surface erosion during intense precipitation events is a significant source of soil nutrient loss in developing countries (Zougmore et al. 2009). Agricultural areas with poorly drained soils or that experience frequent and/or intense rainfall events can have waterlogged soils that become hypoxic. The change in soil redox status under low oxygen can lead to elemental toxicities of Mn, Fe, Al and B that reduce crop yields (Setter et al. 2009), and the production of phytotoxic organic solutes that impair root growth and function (Marchner 1995). Hypoxia can also result in nutrient deficiency since the active transport of ions into root cells is driven by ATP synthesized through the oxygen dependent mitochondrial electron transport chain (Drew 1988; Atwell and Steer 1990). Significant nitrogen losses can also occur under hypoxic conditions through denitrification as nitrate is used as an alternative electron acceptor by microorganisms in the absence of oxygen (Prade and Trolldenier 1990; Marchner 1995).

Carbon sequestration in relation to rainfall

Srinivasarao et al (2009) have reported a **s**ignificant correlation between SOC stock and mean annual rainfall (r = 0.59*; Figure1) indicating that enhanced rainfall will help in sequestration of more carbon in soils.



Effects of increased temperature on nutrient availability

Soil warming can increase nutrient uptake from 100– 300% by enlarging the root surface area and increasing rates of nutrient diffusion and water influx (Ching and Barber 1979; Mackay and Barber 1984). Water soluble nutrients including nitrate, sulfate, Ca, Mg primarily move towards roots through transpiration-driven mass flow (Barber 1995). Since warmer temperatures increase rates of transpiration, plants tend to acquire water soluble nutrients more readily as temperature increases. Temperature increases in the rhizosphere can also stimulate nutrient acquisition by increasing nutrient uptake via faster ion diffusion rates and increased root metabolism. However, any positive effects of warmer temperature on nutrient capture are dependent on adequate soil moisture. If under dry conditions higher temperatures result in extreme vapor pressure deficits that trigger stomatal closure (reducing the water diffusion pathway in leaves) (Abbate et al. 2004), then nutrient acquisition driven by mass flow will decrease (Cramer et al. 2009). Temperature driven soil moisture deficit slows nutrient acquisition as the diffusion pathway to roots becomes longer as ions travel around expanding soil air pockets. Emerging evidence suggests that warmer temperatures have the potential to significantly affect nutrient status by altering plant phenology (Nord and Lynch 2009). The duration of plant developmental stages is extremely sensitive to climate conditions and is particularly responsive to temperature (Cleland et al. 2007). Experimental warming was shown to shorten phenological stages in wheat that resulted in a 9% yield decrease per 1°C increase in temperature. Nord and Lynch (2008) found that genotypes with shorter vegetative growth phases (shortened phenology) had ∼30% decreases in reproductive tissue and seed production in soil with low phosphorus availability because of reduced P acquisition and utilization. High temperature results in increases soil salinization due to a) increased demand of water, b) increased evaporation c) increased salt accumulation in crops via increased transpiration and d) rising sea water level because increased water intrusion. Higher temperature also results in increased volatilization losses of added nitrogen.

Carbon sequestration in relation to temperature

Various schools of thoughts have been reported in the literature to explain the influence of temperature on the carbon sequestration. Srinivasarao et al (2009) have worked out non-significant and negative relationship between the minimum, mean and maximum temperature with the organic stocks from the soils samples collected from different dryland centres of India. They are also opinion that the temperature and rainfall in some parts of the country will continue to remain a potential threat for C sequestration in tropical soils of the Indian subcontinent.

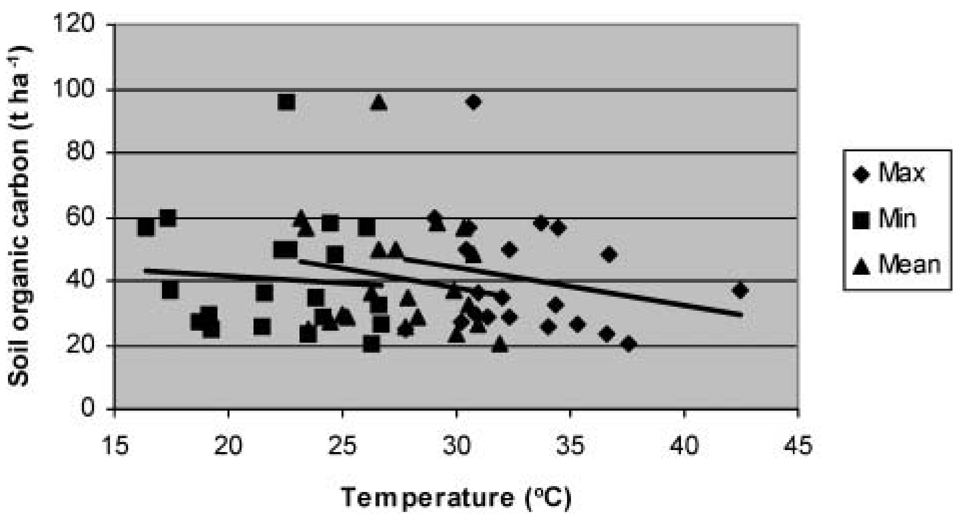


Figure -2-Relationships among maximum, minimum, and mean temperature (C) and soil organic carbon in surface layer (0–15 cm) under rainfed conditions

Increased temperature May Enhance Soil Carbon Storage

The amount of carbon stored above and beneath a unit area of land is basically a function of two biochemical processes, photosynthesis and respiration. For many years, theoretical models of ecosystem dynamics suggested that global warming would reduce both the magnitude and number of terrestrial carbon sinks by increasing ecosystem respiration more than it increased ecosystem photosynthesis. If true, this result would dash all hopes of mitigating CO_2-induced global warming via biological carbon sequestration. However, like model-based predictions of climate change, there are a number of problems with this prediction as well.

The primary problem is the simple fact that most observational evidence does not support the model predictions of reduced soil carbon storage under elevated temperatures. Fitter *et al*. (1999), for example, evaluated the effect of temperature on plant decomposition and soil carbon storage, finding that upland grass ecosystem soils artificially heated by nearly 3°C increased both root production and root death by equivalent amounts. Hence, they concluded that in these ecosystems, elevated temperatures "will have no direct effect on the soil carbon store." Similarly, Johnson *et al*. (2000) warmed Arctic tundra ecosystems *by nearly 6°C for eight full years* and still found *no significant effect* of that major temperature increase on ecosystem respiration. Furthermore, Liski *et al*. (1999) showed that carbon storage in soils of both high- and low-productivity boreal forests in Finland actually *increased* with warmer temperatures along a natural temperature gradient. This discrepancy between model predictions and reality may be due to: (1) ecosystem modelers are over-estimating the temperature dependency of soil respiration, and (2) warming may increase the rate of certain physico-chemical processes that transfer organic carbon to more stable soil organic matter pools, thereby enabling the protected carbon to avoid or more strongly resist decomposition (Thornley and Cannell, 2001).

Elevated carbon dioxide can enhance uptake of nutrients

The concentration of atmospheric carbon dioxide which is predicted to increase in the coming years. Marget et al (1997) have recorded 1.25 times higher water use by wheat under increased carbon dioxide content (750 ppm) as compared 350 ppm. Similarly they have also recorded increased root biomass and root volume has helped the crop in increased uptake of nitrogen, phosphorus and other nutrients (Table.3). Prior (2004) studied the effect of elevated CO_2 on soil carbon and nitrogen dynamics in sorghum [*Sorghum bicolor* (L.) Moench.] under two atmospheric CO_2 levels: (370 [ambient] and 550 $\mu L\ L^{-1}$ [free air CO_2 enrichment; FACE]) and two water treatments (ample water and limited water) on a Trix clay loam (fine, loamy, mixed [calcareous], hyperthermic Typic Torrifluvents) at Maricopa, AZ. The results of their study indicated that after 2 yr of FACE, soil C and N were significantly increased at all soil depths. Water regime had no effect on these measures. Increased total N in the soil was associated with reduced N mineralization under FACE. The potential C turnover was reduced under water deficient conditions at the top soil depth. Carbon turnover was not affected under FACE, implying that the observed increase in soil C with elevated CO_2 may be stable relative to ambient CO_2 conditions suggesting that, over the short-term, a small increase in soil C storage could occur under elevated atmospheric CO_2 conditions in sorghum production systems with differring water regimes

Table.2 – Total plants, roots grain weights and N, P and K content as influenced by carbon dioxide

	60 d				116 d			
	350/'dry'	700/'dry'	350/'wet'	700/'wet'	350/'dry'	700/'dry'	350/'wet'	700/'wet'
Total plant (g per plant)	5·1 (0·5)	5·3 (0·3)	6·3 (0·3)	6·7 (0·1)	12·7 (0·3)	14·1 (0·7)	16·9 (0·7)	17·9 (0·4)
Roots (g per plant)	0·8 (0·1)	1·0 (0·1)	0·9 (0·1)	1·1 (0·1)	1·0 (0·1)	1·3 (0·1)	1·3 (0·1)	1·4 (0·1)
Grain (g per plant)	—	—	—	—	3·9 (0·2)	5·1 (0·3)	6·0 (0·4)	6·8 (0·0)
Total N (mg per plant)	157·4 (8·1)	145·5 (5·0)	189·2 (2·1)	180·8 (3·7)	218·8 (5·5)	232·9 (6·8)	268·3 (7·1)	275·5 (8·0)
Total K (mg per plant)	120·9 (7·0)	102·9 (4·8)	144·3 (3·1)	132·0 (4·1)	180·6 (9·1)	190·7 (8·1)	213·7 (17·2)	188·7 (10·1)
Total P (mg per plant)	10·4 (0·5)	12·3 (0·8)	16·0 (0·3)	17·4 (0·7)	21·8 (0·7)	27·6 (0·3)	37·9 (1·9)	37·1 (2·6)

Data are averages with standard errors in parentheses ($n = 4$).

Elevated carbon dioxide can enhance carbon sequestration

"Soil organic carbon (SOC) is the largest reservoir of organic carbon in the terrestrial biosphere." Cardon *et al*. (2001) studied soil carbon income and outgo in a number of small microcosms of two annual C3 grassland communities (sandstone and serpentine) of contrived high and low soil-nutrient availability that were maintained out-of-doors in open-top chambers at the Jasper Ridge Biological Preserve in Stanford, California from October 1994 through August 1996. They found that the extra CO_2 supplied to half of the mini-ecosystems increased the total root biomass in the serpentine grassland microcosms by a factor of *three* in both the high and low soil-nutrient availability treatments, while it increased total root biomass in the sandstone grassland microcosms by a factor of *four* in both the high and low soil-nutrient availability treatments. Hence, there was a tremendous CO_2-induced increase in the amount of organic material that would eventually become available for incorporation into the soils of both grassland microcosms. Second, with so much new organic matter being added to the soils of the CO_2-erniched microcosms, Cardon *et al*. (2001) felt that previously carbon-limited microbes in these soils would alter their survival strategy and turn from breaking down older more recalcitrant soil organic matter to attack the more abundant and labile *rhizodeposits* being laid down in the newly-carbon-rich soils of the CO_2-enriched microcosms. This *rhizodeposition*, as they defined it, consists of "all deposition of organic carbon from living root systems to soils, including compounds lost through root exudation, sloughing of dead cells during root growth, and fine root turnover," which, as noted above, was dramatically enhanced by atmospheric CO_2 enrichment. Based on their studies they are of the opinion that "an increased retention of carbon in older SOC pools might be expected under elevated relative to ambient CO_2." Hence, not only does atmospheric CO_2 enrichment lead to higher rates of carbon *input* to soils, it apparently leads to slower rates of carbon *withdrawal* from them as well. That's the classical "double whammy" that allows ever more carbon to be socked away in earth's soil bank as the air's CO_2 content continues to rise. And that phenomenon keeps the air's CO_2 rate-of-rise from accelerating, even in the face of yearly increases in anthropogenic CO_2 emissions.

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Nutrient Management Strategies for Minimizing Drought Impacts in Rainfed Agriculture

K. Srinivas
Principal Scientist, CRIDA

Water stress is one of the major limitations to the agricultural productivity worldwide, particularly in warm, arid and semi arid parts of the world. Environmental stresses contribute significantly in reduction of crop yields well below the potential maximum yields. Bray et al. (2000), reported that the relative decreases in potential maximum crop yields (i.e., yields under ideal conditions) associated with abiotic stress factors including drought, vary between 54% and 82%. Therefore, for sustaining food security, a high priority should be given to minimizing the detrimental effects of drought. Drought results in the increased generation of reactive oxygen species (ROS) due to energy accumulation in stressed plants which consume less light energy through photosynthetic carbon fixation. Drought inhibits or slows down photosynthetic carbon fixation mainly through limiting the entry of CO2 into the leaf or directly inhibiting metabolism. The detrimental effects of drought can be minimized by adequate and balanced supply of mineral nutrients. Increasing evidence suggests that mineral-nutrient status of plants plays a critical role in increasing plant resistance to drought stress (Marschner, 1995).

Proper nutrition is the basic need of every living organism. There are now 17 elements which are considered essential for plants to complete their life cycle (Waraich et al., 2011). These essential plant nutrients are divided into two categories; macronutrients and micronutrients. Macronutrients include carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S). Micronutrients are zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), boron (B), molybdenum (Mo), chlorine (Cl) and nickel (Ni). These plant nutrients are not only required for better plant growth and development, but also helpful to alleviate different kinds of abiotic stresses like drought stress. Although silicon (Si) is not essential, it is considered as a beneficial plant nutrient. These plant nutrients are not only required for better plant growth and development, but also helpful to alleviate different kinds of abiotic stresses like drought stress.

Nitrogen

Availability of N and consequently the response to N is closely related to the ability of plant roots to absorb water from soil. When water inside the plant declines below a threshold level, stomata close causing a decrease in transpiration resulting in reduction in water transport through the plant. This in turn, affects the roots' ability to absorb water and nutrients as effectively as under normal transpiration. Kathju et al. (1990) observed that when wheat plants were grown under low (N0P0) and high (N80P80) fertility conditions and water stress was imposed at various stages of a plant's life cycle, increasing intensities of stress adversely affected leaf metabolism and plant performance. However, the performance of plants was better under high fertility conditions, at all stages, under different intensities of water stress. Ashraf et al. (2001) reported that N application minimizes the adverse effect of drought on dry matter and grain yield in pearl millet. This indicates that in dry land agriculture, where water is a limiting factor, N fertilizer application to a reasonable extent helps mitigate the undesirable effects of drought on crop plants.

Phosphorus

It is generally accepted that the uptake of P by crop plants is reduced in dry-soil conditions. Turner (1985) pointed out that P deficiency appears to be one of the earliest effects of mild to moderate drought stress in soil-grown plants. The application of P fertilizer can improve plant growth considerably under drought conditions. The positive effects of P on plant growth under drought can be attributed to increase in stomatal conductance, photosynthesis, higher cell-membrane stability, water relations and water-use efficiency. Ajouri et al. (2004) reported that priming seeds with solutions containing the limiting nutrients under drought conditions (such as P and Zn) can improve seedling establishment. An important approach for increasing P uptake involves taking advantage of the symbiosis between the roots and mycorrhiza, the latter of which enhance both the growth or resistance of plants subjected to drought, and also the uptake of P, Zn, Cu, Mn, and Fe (Bagayoko et al., 2000). Phosphorus improves the root growth and maintains high leaf water potential. The improved root growth results in improved water and nutrient uptake.

Potassium

K nutritional status of plants is known to be of great importance for sustaining high yields under rain-fed conditions. Numerous studies show that the application of K fertilizer mitigates the adverse effects of drought on plant growth. Potassium increases the plant's drought resistance through its functions in stomatal regulation, osmoregulation, energy status, charge balance, protein synthesis and homeostasis. It also maintains turgor pressure and reduces transpiration under drought conditions. Working with wheat, Morgan (1992) showed that the lines displaying high osmotic adjustments had a high accumulation of K_ in their tissues. Potassium nutrition increases crop WUE by utilizing the soil moisture more efficiently than in K-deficient plants. The positive effects of K on water use efficiency may be through promotion of root growth accompanied by a greater uptake of nutrients and water by plants and through the reduction of transpirational water loss.

Increase in severity of drought stress results in corresponding increase in K demand to maintain photosynthesis and protect chloroplasts from oxidative damage. Decrease in photosynthesis caused by drought stress is particularly high in plants supplied with low K, and minimal when K is sufficient. Alleviation of detrimental effects of drought stress, especially on photosynthesis, by sufficient K supply has also been shown in legumes (Sangakkara et al., 2000). In field experiments conducted in Egypt, it was found that decreases in grain yield resulting from restricted irrigation could be greatly eliminated by increasing K supply (Abd El-Hadi et al., 1997). Under water-deficit conditions, K nutrition increases crop tolerance to water stress by utilizing the soil moisture more efficiently than in K-deficient plants. Potassium maintains the osmotic potential and turgor of the cells and regulates the stomatal functioning under water stress conditions. It enhances photosynthetic rate, plant growth and yield under stress conditions.

Calcium

Calcium is considered to play a role in mediating stress response during injury, recovery from injury, and acclimation to stress (Palta, 2000). It has been suggested that Ca is necessary for recovery from drought by activating the plasma membrane enzyme ATPase which is required to pump back the nutrients that were lost in cell damage (Palta, 2000). Intracellular Ca regulates the responses of plants to drought and plays a role in the transduction of drought stress signals in plants, which play an essential role in osmoregulation under this condition.

Magnesium

Mg plays a fundamental role in phloem export of photosynthates from the source to the sink organs, and its deficiency results in dramatic increases in accumulation of carbohydrates in the source leaves. Magnesium increases the root growth and root surface area which helps to increase uptake of water and nutrients by roots and transport of sucrose from leaves to roots. Maintenance of chloroplast structure by improving Mg nutrition enhances the photosynthetic rate under water stress which in turn improves the water use efficiency.

Micro nutrients

The contributions of micro nutrients in enhancing water use efficiency are less well-defined. Micronutrients help in enhancing WUE by activation of certain physiological, biochemical and metabolic processes within the plant body.

- Zn is important for its ability to influence auxin levels and has long been known to be a co-enzyme for production of tryptophane, a precursor to the formation of auxin. Increase in auxin levels due to Zn application enhances the root growth which inturn improves the drought tolerance in plants. As indicated above, normal auxin functions are likely to be disrupted in drought condition. Maintaining adequate hormone levels gives a competitive advantage to withstand abiotic stresses.
- Boron improves the drought tolerance in plants by improving sugar transport, flower retention, pollen formation and seed germination. Seed and grain production are also increased with proper B supply.
- Cu nutrition alleviates the adverse affects of drought by reducing dieback of stems and twigs, yellowing of leaves, stunted growth, pale green leaves that wither easily, and improves CHO and nitrogen metabolism which in turn improves the growth of plants.
- Si increases water use efficiency by reducing leaf transpiration and the water flow rate in the xylem vessels and facilitates water uptake and transport under drought conditions.
- Micronutrients, along with macronutrients reduce the toxicity of reactive oxygen species (ROS) produced under water-limited conditions by increasing the concentration of antioxidants like superoxide dismutase (SOD); Catalase (CAT) and peroxidase (POD) in the plant cells. These antioxidants scavenge ROS and reduce photo-oxidation and maintain the integrity of chloroplast membrane and increase the photosynthetic rate in the crop plants which in turn enhances the WUE.
- Micronutrients like Fe, B, Mn and Mo alleviate the adverse effects of drought indirectly by activating the physiological, biochemical and metabolic processes in the plants.

Management practices

Drought conditions induce deficiencies of nutrients which in turn reduces the plant's ability to withstand drought. Foliar application of the following nutrients depending upon the occurrence of their efficiencies can mitigate the water-stress induced nutritional imbalance in crops.

a. 2 % DAP

b. 0.5 to 1 % potassium chloride (KCl)
c. 0.5 % Zinc sulphate
d. 0.5 – 1.0 % Ferrous sulphate + 1 % urea
e. 0.3 % Boric acid
f. Foliar spray of 2%c DAP + 1% KCl (MOP) during critical stages of flowering and grain formation
g. Foliar spray of 0.5% zinc sulphate + 0.3 % boric acid + 0.5 % Ferrous sulphate + 1% urea during critical stages of moisture stress

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Concepts of Conservation Agriculture and crop residue management for soil health improvement in rainfed areas

G.Pratibha
Central Research Institute for Dryland Agriculture, Hyderabad 500059

India is endowed with a rich and vast diversity of natural resources, particularly soil, water, weather, multipurpose trees and bio-diversity. To realize the potential of production system on a sustained basis, efficient management of the natural resources is very crucial. With the advent of high-yielding crop varieties and intensive cultivation, the food grain production has increased from 51 million tones (mt) in 1950-51 to a record figure of 210 mt during 2007-2008. This impressive achievement has pulled the country in to self-sufficiency for food demand. With adoption of intensive agriculture to meet the varied growing demands for food, fuel, fiver, feed, fertilizer and products in the recent year, the natural resources are however, put under intense strain resulting in fast degradation and lowering of their production efficiency. Even in high-yielding areas where soils are not considered to be degraded, crops require ever increasing input to maintain yields. In the frame of the recent food crisis, it is clear that agriculture should not only be high yielding, but also sustainable. Human efforts to produce ever greater amounts of food leave their mark on our environment.

Despite the availability of improved technologies the potential increase in production is not attained because of poor cropping system management and degradation of natural resources. Land degradation is a major threat to our food and environmental security. A major factor responsible for the degradation of the natural resources is soil erosion. 150 m ha of land is degraded constituting 45.5% of total geographical area. The area degraded by water and wind erosion is 109.7 and 11.7 m ha respectively. The area under water logging, salinization/alkalization and other problems are 9.0,9.2 and 10.3 m ha respectively. In general soil erosion is more severe in mountainous than undulating areas. Their rate of natural erosion for the world is of the order of 1.5 to 7.0 t/ha/year for the mountainous region and 0.1-7 t/ha/year for the undulation plains. Erosion by water is most serious degradation problem in the Indian context. It has been estimated that soil erosion was taking place at an average rate of 16.35t/ha /year totaling 5,334 mt/year,nearly 29% of the total eroded soil was parentally loss to the sea and nearly 10% was deposited in reservoirs, resulting in the reduction of their storage capacity by 1-2% annually. The remaining 61% of the eroded soil was transferred from one place to another. The annual water erosion rate values ranged from <5 t/ha/year to more than 80 t/ha/year. The widespread erosion in the hilly catchments area is resulting in excessive siltation of multipurpose reservoirs and other water-bodies to the country at rates higher than their designed capacity. Persistent use of conventional farming practices based on extensive tillage, and especially when combined with in situ burning of crop residues, have magnified soil erosion losses and the soil resource base has been steadily degraded (Montgomery, 2007). However, today such production increases must be accomplished sustainably, by minimizing negative environmental effects and, equally important, providing increased income to help improve the livelihoods of those employed in agricultural production.

Hence crop production in the next decade will have to produce more food from less land by making more efficient use of natural resources—and with minimal impact on the environment. Only by doing so food production can keep pace with demand, while the land's productivity is preserved for future generations. This is a tall order for agricultural scientists, extension personnel, and farmers. Use of productive but more sustainable management practices like conservation agriculture can help solve this problem. In this context globally conservation agriculture (CA) has opened a new paradigm as it has potential to increase resource use efficiency, water productivity, mitigation of climate change (increasing carbon sequestration and reducing the GHG emissions) in rainfed regions. CA includes the key principles like minimum soil disturbance, crop rotations and residue retention on the soil surface

What is conservation Agriculture

Conservation Agriculture (CA) refers to the system of raising crops without tilling the soil while retaining the crop residues on the soil surface Usually, the retention of 30% surface cover by residues characterizes the lower limit of classification for conservation-tillage. The concept of CA has evolved from the zero tillage (ZT) technique.

More often the conservation agriculture and resource-conserving technologies (RCTs) were used as synonyms. But there is a difference between this two and hence an attempt was made to make a sharper distinction between this two. All RCTs may not be part of CA systems. Resource-conserving technologies have been developed in order to reduce the use and damage to natural resources through agricultural production, increase the efficiency of resource utilization. Most of these technologies target the two most crucial natural resources: water and soil, but some also affect the efficiency of other production resources and inputs (e.g. labour, farm power and fertilizer). The resource conservation technologies may be new varieties that use fertilizers more efficiently, Zero or reduced tillage practices that save fuel and improve plot-level water productivity may be considered as RCTs, as may land leveling practices that help save water. There are many, many more in contrast, conservation agriculture practices will only refer to the RCTs with the following characteristics:

- Soil cover, particularly through the retention of crop residues on the soil surface;
- Sensible, profitable rotations; and
- A minimum level of soil movement, e.g., reduced or zero tillage.

The distinction between RCTs and CA is important because some RCTs may be attractive in the near- term, may be unsustainable in the longer-term. An example of this is the use of zero tillage without residue retention and without suitable rotations which, under some circumstances, can be more harmful to agro ecosystem productivity and resource quality than a continuation of conventional practices (Sayre, 2000). Hence, the CA essentially consists of all the three components and addresses on enhanced concept of the complete agricultural system to get the improved productivity and improve the resource base.

The key features which characterize CA include:

a) Minimum soil disturbance by adopting no-tillage and by direct planting through the soil cover without seedbed preparation; and minimum traffic for agricultural operations,
b) Maintenance of a permanent vegetative soil cover or mulch to protect the soil surface;

c) Adopt spatial and temporal crop sequencing/crop rotation to derive maximum benefits from inputs and minimize adverse environmental impacts.

1. Minimizing or suppressing soil tillage

In conservation agriculture systems, the soil should ideally never been tilled, or as little as possible. The objective is to favour a better cohesion between soil aggregates, decrease soil organic matter mineralisation and allow the development of soil biota. While no tillage is considered as the ideal, in many cases, however, farmers use reduced tillage, especially when they start to shift towards the practice of CA.

2. Protecting the soil surface through mulch

Under CA, crop residues or cover crops should be main- tained on the soil surface as a dead or live mulch. The objective is to protect the soil against weather aggressions and water erosion, to maintain soil moisture , to suppress weed growth and to provide shelter and food for the soil biota . The biomass produced in the system is kept on the soil surface rather than incorporated into the soil or burnt, which provides physical protection for the soil against agents of soil degradation and food for the soil life. When the crop residues are retained on soil surface in combination with NT, it initiates processes that lead to improved soil quality and overall resource conservation. Therefore, zero/minimum tillage and maintenance of soil cover in the form of crop residues or cover crops are important elements of CA. At the same time varied crop rotations involving legumes, are important to manage pest and disease problems and improve soil quality through biological nitrogen fixation and addition of organic matter

3. Rotating and/or associating crops

Use of crop rotations or intercropping is considered essential in CA systems (Calegari 2001), as it offers an option for pest/ weed management that is no longer realized through soil tillage. Additionally, achieving greater biodiversity at the field and farm level favours a better use of natural resources, a more even distribution of labour and more diversified farm incomes. Over the past 2-3 decades globally, CA has emerged as a way of transition to the sustainability of intensive production systems. It permits management of water and soils for agricultural production without excessively disturbing the soil, while protecting it from the processes that contribute to degradation like erosion, compaction, aggregate breakdown etc, and this also has the potential to emerge as an effective strategy to the increasing concerns of serious and widespread natural resources degradation and environmental pollution, which accompanied the adoption and promotion of green revolution technologies, since the early seventies, permits management of soils for agricultural production without excessively disturbing the soil, while protecting it from the processes that contribute to degradation e.g. erosion, compaction, aggregate breakdown, loss in organic matter, leaching of nutrients etc. Conservation agriculture is a way to achieve goals of enhanced productivity and profitability while protecting natural resources and environment, an example of a win win situation. In the conventional systems, soil tillage is a necessary requirement to produce a crop, while tillage does not form a part of this strategy in CA. In the conventional system , there is a gradual decline in soil organic matter through accelerated oxidation due to intensive tillage and burning of crop residues this causes pollution, green house gases emission and loss of valuable plant nutrients. Where as when the crop residues are retained on soil surface in combination with no tillage, it initiates processes that lead to improved soil quality and overall resource enhancement. Benefits of CA have been demonstrated through its large-scale adoption in many socioeconomic and agro-ecological situations in different countries the world over.

Benefits to Farmers

These include:

- Reduced cultivation cost through savings in labour, time and farm power.
- Improved and stable yields with reduced use of inputs (fertilizers, pesticides).
- In case of mechanised farmers, longer life and minimum repair of tractors and less water, power and much lower fuel consumption.
- Benefits of CA come about over a period of time and in some cases, might appear less profitable in the initial years.

Benefits to Natural Resources

These include:

- The residue left on the topsoil acts as a barrier, intercepts rainfall, absorbs energy and reduces the impact of rainfall on the spoil and releases the energy more slowly for infiltration of water into the soil and thereby reduces the the runoff velocity and increases time for water to infiltrate;.thereby it reduces erosion and runoff and soil degradation.
- Reduced erosion can lead to regional benefits such as reduced rate of siltation of water courses and increased recharge of aquifers
- Gradual decomposition of surface residues leads to increased organic matter and biological activity resulting in improved capacity of soils to retain and regulate water and nutrient availability and supply.
- Improved biological activity and diversity in the soil including natural predators and competitors.
- Reduced pollution of surface and ground water from chemicals and pesticides, resulting from improved inputs use efficiency.
- Saves non-renewable energy use and increased carbon sequestration.
- Adoption of CA can improve SOC concentration and stock in the surface layer, enhance aggregation, improve water infiltration rate, increase plant-available water storage, and restore soil health,
- Use of legume-based and other complex rotations benefit soil quality even beyond the expected reduction in incidence of pests and pathogens,
- A cover crop (e.g., lupin) grown in an off-season can improve C sequestration
- CA is not a “one-size-fits-all” solution and requires a strong flexibility and fine-tuning under site-specific conditions,
- The yield benefits of CA can be realized only when plant nutrients are not limiting,
- CA practices increases water productivity, nutrient use efffeciency crop yields, even when little or no mulch through crop residues was achieved.
- CA controls weeds by a combination of crop rotation, mulching
- CA is an important climate change mitigation strategy since it helps in greater retention of C in the soil. Reduced fuel consumption in farming for tillage, water pumping, reduced residue burning, under CA practices lead in remarkable reduction in emission of greenhouse gases into the atmosphere.
- CA can help to adapt to climate change induced water stress through increased water infiltration, improved soil water holding capacity and reduced evaporation of stored soil moisture

Conservation Agriculture Global Scenario

According to current estimates globally, CA systems are being adopted in some 96 million ha, largely in the rainfed areas and that the area under CA is increasing rapidly. USA has been the pioneer country in adopting CA systems and currently more than 18 million ha land is under such system. The spread of CA in US has been the result of a combination of public pressure to fight erosion, a strong tillage and conservation related research and education backup and public incentives to adopt reduced tillage systems. Other countries where CA practices have now been widely adopted for many years include Australia, Argentina, Brazil and Canada. In many countries of Latin America CA systems are fast catching up. Some states of Brazil have adopted an official policy to promote CA. In Costa Rica a separate Department of Conservation Agriculture has been set up. A redeeming features about CA systems in many of these countries is that these have come more as farmers' or community led initiatives rather than a result of the usual research extension system efforts. Farmers practising CA in many countries in South America are highly organized into local, regional and national farmers' organizations, which are supported by institutions from both south and north America. Spread of CA systems is relatively less in Europe as compared to countries mentioned above. While extensive research over the past two decades in Europe has demonstrated the potential benefits of CA yet the evolution of practice its has been slower in EU countries vis-a-vis. other parts of the world possibly due to inadequate institutional support. France and Spain are the two countries where CA was being followed in about one million ha of area under annual crops. In Europe a European Conservation Agriculture Federation, ECAF, a regional lobby group has been founded. This body unites national associations in UK, France, Germany, Italy, Portugal and Spain. Conservation agriculture is being adopted to varying degrees in countries of south-east Asia viz. Japan, Malaysia, Indonesia, Korea, the Philippines, Taiwan, Sri Lanka and Thailand. Central Asia is another area prospective of CA. In South Asia CA systems would need to reflect the unique elements of intensively cultivated irrigated cropping systems with contrasting edaphic needs, rainfed systems with monsoonic climate features, etc. Concerted efforts of Rice-Wheat Consortium for the Indo-Gangetic Plains (IGP) a CG initiative and the national research system of the countries of the region (Bangladesh, India, Nepal and Pakistan) over the past decade or so are now leading to increasing adoption of CA technologies chiefly for sowing wheat crop. According to recent assessments in more than one million ha area wheat was planted using a no-till seed drill in the region. Experiences from Pakistan (Punjab, Sindh and Baluchistan provinces) showed that with zero-tillage technology farmers were able to save on land preparation costs by about Rs. 2500 per ha and reduce diesel consumption by 50 to 60 litres per ha. Zero tillage allows timely sowing of wheat, enables uniform drilling of seed, improves fertilizers use efficiency, saves water and increases yield up to 20 percent. The number of zero tillage drills in Pakistan increased from just 13 in 1998-99 to more than 5000 in 2003-2004. Farmers have also adopted bed planting of wheat, cotton and rice. Wheat straw chopper has also been adapted to overcome planting problems in wheat crop residue. Bed and furrow planting of cotton is finding favour with the farmers due to savings in irrigation water and related benefits of improved use-efficiency of applied fertilizers, reduced soil crusting, etc. There is widespread use of laser land leveller which helps in curtailing irrigation, reduces labour requirement, enhances cultivated area and improves overall productivity. In 2003-04 around 225 laser land levellers were being used.

Conservation Agriculture in Rainfed Semi-arid and Arid Regions

Rainfed semi-arid and arid regions are characterized by variable and unpredictable rainfall, structurally unstable soils and low overall productivity. Results of most research station studies show that zero/ reduced tillage system without crop residues left on the soil surface have no particular advantage because much of the rainfall is lost as runoff due to rapid surface sealing nature of soils. It would therefore appear that no tillage alone in the absence of soil cover is unlikely to become a favored practice. However, overall productivity and residue availability being low and demand of limited residues for livestock feed being high also poses a major limitation for residue use as soil cover in the arid and semi-arid regions. In the semi-arid regions there is wide variability in rainfall and its distribution and nature of soils. It would appear that there is need to identify situations where availability of even moderate amount of residues can be combined with reduced tillage to enhance soil quality and efficient use of rainwater. There appears no doubt that managing zero-tillage system requires a higher level of management vis-a-vis conventional crop production systems. Also there exists sufficient knowledge to show that benefits of CA mainly consist of reversing the process of degradation and that its advantage in terms of crop productivity may accrue only gradually.

CA or no-till farming has spread mostly in the rainfed agriculture allover the world. However, in India its success is more in irrigated belt of the Indo-Gangetic plains. Considering the severe problems of land degradation due to runoff induced soil erosion, rainfed areas particularly in arid and semi-arid regions requires the practice of CA more than the irrigated areas to ensure a sustainable production.

Unlike the homogenous growing environment of the IGP, the production systems in arid and semi-arid regions are quite heterogeneous and diverse in terms of land and ware management and cropping systems. These include the core rainfed areas which cover up to 60-70% of the net sown area and the irrigated production systems in the remaining 30-40% area. The rainfed cropping systems are mostly single cropped in the red soil areas while in the black soil regions; a second crop is taken on the residual moisture. In *rabi* black soils farmers keep lands fallow during *kharif* and grow *rabi* crop on conserved moisture. The rainfall ranges from >500 mm in arid to 1000 mm in dry sub-humid zones. Alfisols, vertisols, inceptisols and entisols are the major soil orders. Soils are slopy and highly degraded due to continued erosion by water and wind. Sealing, crusting, subsurface hard pans and cracking are the key constraints which cause high erosion and impede infiltration of rainfall. The choice and type of tillage largely depend on the soil type and rainfall. Leaving crop residue on the surface is another important component of CA, but in rainfed areas due to its competing uses as fodder, little or no residues are available for surface application.

Experience from several experiments in the country showed that minimum or reduced tillage does not offer any advantage over conventional tillage in terms of grain yield without retention of surface residue. Leaving surface residue is key to control runoff, soil erosion and hard setting in rainfed areas which are the key problems. In view of the shortage of residues in rainfed areas, several alternatives strategies have emerged for generation of residues either through in situ cultivation and incorporation as a cover crop or harvesting from perennial plants grown on bunds and adding the green leaves as manure cum mulching. Agro forestry and alley cropping systems are other options where biomass generation can be integrated along with crop production. This indicates that the concept of CA has to be understood in a broader perspective in arid and semi-arid agriculture which include an array of practices like reduced tillage, land treatments for water conservation, on-farm and off-farm biomass generation and agro forestry. Here, conservation tillage with reduced retention on surface is more appropriate than zero tillage which is emphasized in irrigated agriculture.

Constraints in Adopting Conservation Agriculture Systems

In spite of several advantages CA offers, there is very slow adoption of CA worldwide except in countries like Brazil, Argentina, Australia, and the USA due to various problems encountered during its adoption. These problems poses a challenge both for the scientific community and the farmers to overcome the past mindset and explore the opportunities that CA offers for natural resources improvement. The main constraint for adoption of CA is Competitive Uses of Crop Residues

- Benefits of CA are most directly attributed to the mulch of crop residues retained in the field, limited availability of crop residues is under many farming conditions an important constraint for adoption of CA practices. Since crop residues, in geneeral in particular cereal and legume residues provide highly valued fodder for livestock in smallholder farming systems in rainfed regions of India. In rainfed regions fodder/feed is often in critically short supply, given typical small farm size and limited common land for grazing.
- Termite infestation is alos another major constraint for retaining crop residues on the soil. For example 80% of sorghum residue was lost after 4 months in the presence of macro-fauna (termite), while only 1% disappeared in the absence of macro-fauna.
- Severe weed infestation particularly during initial years of adoption is one major hindrance to motivate the farmers to adopt CA as not tilling the soil commonly results in increased weed pressure.
- The presence of crop residues on the soil surface and NT in CA pose a big challenge for seeding and planting of crops
- Conservation agriculture systems represent a major departure from the past ways of doing things. This implies that the whole range of practices including planting and harvesting, water and nutrient management, diseases and pest control etc. need to be evolved, evaluated and matched in the context of new systems.

Ways to overcome the constraints in rainfed regions

Elimination of biomass burning is important to success of CA and enhancing resilience against vagaries of changing and uncertain climate .

Adoption of CA in conjunction with appropriate policies, especially those which promote residue retention and growing a cover crop in the rotation cycle, can also enhance biodiversity CA can also be adopted with agroforestry systems, or systems of growing crops in combination with trees and woody perennials in sustainable intensification of agroecosystems for improving both productivity and the environment. mulch retention, legume-based rotation, Use of green manure crops.

Harvesting the crop residues at higher height to increase the crop residues. Intercropping systems growing cover crops with the main crops may be another feasible way of producing sufficient biomass for CA Brown manuring Improved fodder sources should also be part of the improved management package. Weeding before seed setting is essential to reduce weed intensity in the longer- term. Similarly, controlling weeds growing on field bunds and periphery is a must as they are important source of weed seed bank.

How Long Does It Take to See Benefits

Usually the full benefits of CA take time and, in fact, the initial transition years may present problems that influence farmers to disadopt the technology. Weeds are often a major initial problem that required integrated weed management over time to get them under control. Soil physical and biological health also takes time to develop. Three to seven years may be needed for all the benefits to take hold. But in the meantime, farmer save on costs of production and time and usually get similar or better yields than with conventional systems. Farmers should be encouraged to continue this sustainable pract ice and correct problems as they arise.

Conclusions

Crop production in the next decade will have to produce more food from less land by making more efficient use of natural resources—and with minimal impact on the environment. Only by doing so can food production keep pace with demand, while land's productivity is preserved for future generations. This is a tall order for agricultural scientists, extension personnel, and farmers. Use of productive but more sustainable management practices described in this paper can help solve this problem. Crop and soil management systems that improve soil health parameters (physical, biological, and chemical) and reduce farmer costs are essential. Development of appropriate equipment to allow these systems to be successfully adopted by farmers is a prerequisite for success. Overcoming traditional mindsets about tillage by promoting farmer experimentation with this technology in a participatory way will help accelerate adoption. Encouraging donors to support this long-term, applied research with sustainable funding is also an urgent need.

MULCHING PRACTICES IN HORTICULTURAL BASED CROPPING SYSTEM INRAINFED AREAS

A.G.K.Reddy
Central Research Institute for Dryland Agriculture, Hyderabad 500059

Introduction

Mulching is the process or practice of covering the soil/ground to make more favourable conditions for plant growth, development and efficient crop production. Mulch technical term means 'covering of soil'.While natural mulches such as leaf, straw, dead leaves and compost have been used for centuries, during the last 60 years the advent of synthetic materials has altered the methods and benefits of mulching.The research as well as field data available on effect of synthetic mulches make a vast volume of useful literature. When compared to other mulches plastic mulches are completely impermeable to water; it therefore prevents direct evaporation of moisture from the soil and thus limits the water losses and soil erosion over the surface. In this manner it plays a positive role in water conservation.The suppression of evaporation also has a supplementary effect; it prevents the rise of water containing salt, which is important in countries with high salt content water resources.

Advantages of plastic mulching

1. It is completely impermeable to water.
2. It prevents the direct evaporation of moisture from the soil and thus limits the water losses and conserves moisture.
3. By evaporation suppression, it prevents the rise of water containing salts.
4. Mulch can facilitate fertilizer placement and reduce the loss of plant nutrient through leaching.
5. Mulches can also provide a barrier to soil pathogens
6. Opaque mulches prevent germination of annual weeds from receiving light
7. Reflective mulches will repel certain insects
8. Mulches maintain a warm temperature even during nighttime which enables seeds to germinate quickly and for young plants to rapidly establish a strong root growth system.
9. Synthetic mulches play a major role in soil solarisation process.
10. Mulches develop a microclimatic underside of the sheet, which is higher in carbon- di-oxide due to the higher level of microbial activity.
11. Under mulch, the soil structure is maintained during cropping period
12. Early germination almost 2-3 days.
13. Better nodulation in crops like Groundnut.
14. Less nematodes population.
15. Water erosion is completely averted since soil is completely covered form bearing action of rain drops.
16. When compared to organic mulches, it serves for a longer period.

Moisture conservation

- Plastic film with its moisture barrier properties does not allow the soil moisture to escape Water that evaporates from the soil surface under mulch film, condenses on the lower surface of the film and falls back as droplets.

- Thus moisture is preserved for several days and increases the period between two irrigations.
- The irrigation water or rainfall either moves into the soil thru holes on the mulch around the plant area or through the un-mulched area.


Weed control

- Black plastic film does not allow the sunlight to pass through on to the soil
- Photosynthesis does not take place in the absence of sunlight below black film hence, it arrests weed growth


Areas of application

Mulching is mainly employed for

a. Moisture conservation in rainfed areas
b. Reduction of irrigation frequency and water saving in irrigated areas
c. Soil temperature moderation in greenhouse cultivation
d. Soil solorisation for control of soil borne diseases
e. Reduce the rain impact, prevent soil erosion and maintain soil structure
f. In places where high value crops only to be cultivated

Types of mulches

Basically, there are two types of mulches depending upon the material used as mulching. They are as under:

a. Organic mulches

The organic materials such as crop residues & by products, farm yard manure & by products of timber industry, when used for mulching, are known as organic mulches. Organic mulches create no post utilization disposal problem but their availability is an issue.

b. In-Organic mulches (Plastic mulches)

The in-organic materials such as plastic films, when used for mulching, are known as in-organic mulches may not be available at all times & places, mulches can be made available in different colours & thickness to obtain the desired results

A wide range of plastic films based on different types of polymers have all been evaluated for mulching at various periods in the 1960s. LDPE, HDPE and flexible PVC have all been used and although there were some technical performance differences between them, they were of minor nature. Owing to its greater permeability to long wave radiation which can increase the temperature around plants during the night times, polyethylene is preferred. Today the because it is more economic in use.

Basic properties of mulch film

a. Air proof so as not to permit any moisture vapour to escape.
b. Thermal proof for preservation of temperature and prevention of evaporation c. Durable at least for one crop season

Types of plastic mulches

1. Black mulches
2. Clear or transparent mulches
3. Two sided colour mulches
    a. Yellow/black
    b. White/black
    c. Silver/black
    d. Red/black
4. Degradable mulches
    a. Photo-degradable
    b. Bio-degradable

By proper selection of plastic mulch composition – colour & thickness, it is possible to precisely control the soil environment.

1. **Black mulches**

The black plastic film does not allow sunlight to pass through onto the soil. Thus, photosynthesis does not take place in soil in absence of sunlight below the black film. Hence, it arrests weed growth completely. The black plastic mulch is helpful in conserving moisture and controlling weed growth. However, it may increase the soil temperature.

It has been reported that during hot climate conditions, using plastic nets and non-woven fabrics (layer of polyester or polyvinyl alcohol) in place of black mulch film is also helpful in increasing yield marginally of vegetables, especially that of leafy vegetables.

2. **Clear or Transparent mulches**

The transparent film will allow sunlight to pass through and the weeds will grow. However, by using herbicides coating on the inner side of film weed growth can be checked.

The transparent film is quite successful as soil solarization film or disinfecting the soil in order to reduce soil borne diseases and some weeds. This application is quite successful in nursery raising by solarising the beds before sowing seeds for nursery raising, which gives near 100% seed germination & disease free nursery.

While the black film has proved to be effective in plains to keep crop cool during summer, the transparent film is effective in hilly areas for raising soil temperature in cold climatic conditions during winter.

3. Two – side Colour Mulches

Wavelength selective or photo-selective films (also called two-side coloured) are designed to absorb specific wavelengths of the sun's radiation, which changes the spectrum of the sunlight passing through the film or being reflected back into the plant canopy. These light changes can have a marked effect on plant growth & development. These films enable growers to control different plant properties such as leaf & fruit size, colour, root development, yield, branching, plant height growth, inter node length, time of flowering, bloom size, strengthen plant stems, encourage fruit to grow lower down on plants, and aid in disease control by keeping insect away. The effects are warming of soil temperature, blocking weed growth, increasing colour saturation of developing fruit & increasing carbohydrate transport to developing fruit.

Compared to black mulches, wavelength selective mulches re-emit less heat, thus maintaining lower leaf temperatures, alter red-far-red light balance leading to phytochrome mediated changes in the plant morphology, and reflect more UV rays, which repels insects & pests such as aphids, thrips & whiteflies, who transmit viruses. The white/black, silver/black and aluminized black mulches generally maintain cooler root zone temperatures, thus suitable for most Indian regions. Effects of some of the coloured mulches are given below:

Yellow/black – attracts certain insects & thus acts as trap for them, which prevents disease.

White/black – cools the soil.

Silver/black – cools the soil, though not to the extent of white/black film & repels some aphids & thrips.

Red/black – partially translucent allowing radiation to pass through & warm soil but also reflects radiation back into plant canopy changing ratio of R:FR light, which results in changes in plant vegetative, flower development & metabolism to early fruiting & increased yields in some fruit & vegetable crops.

In the recent past, coloured mulches have gained interest. However, research results with regard to their effectiveness have been mixed and inconsistent. Some research has indicated control over plant height and plant structure by certain coloured films that vary the reflected light quality in the plant canopy. Some coloured films have been implicated in reducing insects populations on plants. Some research has even matched mulch colour with crops giving best yield responses. For example red for tomato and blue for brinjal. However, there is a need for trying further before making any recommendation on coloured mulches and comparing them with standard black or white-on-black or silver-on-black films currently in use.

4. Degradable Mulches

a. Photo-degradable mulches

   This type of plastic mulch film gets disintegrated under sunlight over the designated mulching period.

b. Bio-degradable mulches

   This type of plastic mulch film gets disintegrated under natural environmental conditions & gets mixed in soil after mulching period.

Importance of parameters of the plastic film

Thickness of film

In plastic mulching, the thickness of mulch film should be in accordance with type & age of crops. Economics suggest that the film thickness should be the minimum possible commensurate with desired life & strength. The recommended thickness of mulch films for different crops is as under:

Thickness (microns)	Crops Recommended
7	Groundnut
20-25	Annual – short duration crops
40-50	Biennial – medium duration crops
50-100	Perennial – long duration crops

Extent of surface to be covered under film

% coverage	Crops Recommended
20-25	All creeper crops
40-50	Initial stage of orchard crops
40-60	Fruit crops & cucurbitaceous
70-80	Vegetables, papaya, pineapple etc.
90-100	Soil solarization

Calculation of mulch film requirement (approximately)

Thickness			Area coverage (m^2/kg)	Weight (g/m^2)
Micron	Gauge	mm		
7	28	0.007	144	6.9
20	80	0.02	54	18.4
25	100	0.025	42	23
40	160	0.04	26	38
50	200	0.05	21	46
100	400	0.01	11	93
200	800	0.020	5.3	209
250	1000	0.025	4.29	233

b) Width

This depends upon the inter row spacing. Normally a one to one and half meter width film can be easily adapted to different conditions.

c) Perforations

The perforations may be advantageous under some situations and disadvantageous for some other situation. The capillary movement of water and fertilizer distribution will be better and more uniform under unperforated condition. But for prevention of water stagnation around the plants, perforation is better. But it has got the disadvantages of encouraging weed growth.

d) Mulch colour

The colour of the mulch affects

i. Soil temperature
ii. Temperature of air around the plants
iii. Soil salinity
   a. Due to lesser quantity of water used
   b. Due to reduction in evaporation and prevention of upward movement of water.

Transparent film - Deposits more salt on soil surface

Black film - Restricts water movement and upward movement of salt is reduced.

iv. Weed flora - Black film
v. Insect control - Opaque while film acts as golden colour and attracts insects


Selection of mulch

The selection of mulches depends upon the ecological situations and primary and secondary aspects of mulching

Rainy season	-	Perforated mulch
Orchard and plantation	-	Thicker mulch
Soil solarisation	-	Thin transparent film
Weed control through solarisation	-	Transparent film
Weed control in cropped land	-	Black film
Sandy soil	-	Black film
Saline water use	-	Black film
Summer cropped land	-	White film
Insect repellent	-	Silver colour film
Early germination	-	Thinner film

Methods of mulching

- Orchard/Fruit/Established trees
- Mulching area should preferably be equivalent to the canopy of the plant.
- Required size of mulch film is cut from the main roll.
- Clean the required area by removing the stones, pebbles, weeds etc.
- Till the soil well and apply a little quantity of water before mulching
- Small trench could be made around the periphery of the mulching area to facilitate anchoring of the mulch film.
- Cover the film to the entire area around the tree and the end should be buried in the ground.
- Semi circular holes could be made at four corners of the film in order to facilitate water movement.
- The position of the slit/opening should be parallel to the wind direction

Cover the corners of the film with 4-6 inches of soil on all sides to keep the film in position.

- In hard soil, make a trench of 1'x1'x2' depth on four corners of the mulching area and fill it up with gravel or stones, cover the trenches with the mulch film and allow the water to pass through the mulch to the trenches via semi circular holes on the film

Mulch Laying Techniques

i. Mulch should be laid on a non-windy condition

ii. The mulch material should be held tight without any crease and laid on the bed

iii. The borders (10 cm) should be anchored inside the soil in about 7-10 cm deep in small furrows at an angle of 45°.

Pre planting mulch:

The mulch material should be punctured at the required distances as per crop spacing and laid on the bed. The seeds/seedlings should be sown/transplanted in the holes.

Mulching techniques for Vegetables /close space crop

- Very thin film is used for short duration crops like vegetables.
- Required length of film for one row of crop is taken and folded in 'thaan' form at every one metre along the length of the film.
- Round holes are made at the center of the film using a punch or a bigger diameter pipe and a hammer or a heated pipe end could be used.
- One end of the mulch film (along width) is anchored in the soil and the film is unrolled along the length of the row of planting.
- Till the soil well and apply the required quantity of FYM and fertilizer before mulching.
- Mulch film is then inserted (4-6") into the soil on all sides to keep it intact
- Seeds are sown directly through the holes made on the mulch film.

- In case of transplanted crops, the seedlings could be planted directly into the hole.
- For mulching established seedlings, the process of punching the hole is the same.

  One end of the film along the width is burried in the soil and the mulch film is then unrolled over the saplings. During the process of unrolling, the saplings are held in the hand and inserted into the holes on the mulch film from the bottom side, so that it could spread on the topside.

Precautions for Mulch Laying

- Do not stretch the film very tightly. It should be loose enough to overcome the expansion and shrinkage conditions caused by temperature and the impacts of cultural operation.
- The slackness for black film should be more as the expansion, shrinkage phenomenon is maximum in this color.
- The film should not be laid on the hottest time of the day, when the film will be in expanded condition.

Removal of mulch

In case the mulch film needs to be used for more than one season (thicker film) the plant is cut at its base near the film and the film is removed and used.

By compounding appropriate additives into the plastics it is possible to produce a film, which, after exposure to light (solar radiation) will start to breakup at a pre determined time and eventually disintegrated into very small friable fragments. The time period can be 60, 90, 120 or 150 days and for maize a 60-day photodegradable mulch is used. However there are still some further problems to resolve. It has been observed that the edges of the mulch, which are buried to secure the mulch to the soil, remain intact and become a litter problem when brought to the surface during the post-harvest ploughing. Currently much development effort is being made to find a satisfactory solution to this problem.

In direct contrast in developing countries which have agricultural labour available a different approach can be made. For example in the people Republic of China trials have been made using a plastic mulch of 15 micron thickness on a sugarcane crop. After the cuttings have been planted through the mulch they are left to grow for a period of one month. Then the mulch is removed by hand and wound up so that it can be utilized for a second season. A yield increase of 26% was obtained.

These two examples not only demonstrated the diversity of mechanisms available for resolving the problems of mulch removed, but also illustrate the different technique, which have been developed in different countries. It also indicates the necessity for each country to adapt and develop mulching technique to meet its own specific requirements of climate, resources and economics. To undertake such technology development there is a specific requirement that both plastics and agricultural development facilities are available.

Irrigation practices under mulching:

- In drip irrigation the lateral pipelines are laid under the mulch film
- In case inter-cultivation need to be carried out, it is better to keep the laterals and drippers on top of the mulch film and regulate the flow of water through a small pipe or through the holes made on the mulch film

 

- In flooding the irrigation water passes through the semi circular holes on the mulch sheet.

Conclusions on basis of experiments conducted so for

1. Flexible PVC film is suitable for mulching. PVC film shows the expected over all advantages of mulch irrigation such as conservation of moisture and control of weed growth.
2. Savings in water appear to be the main advantage and such savings are found to vary from 20% to as high as 75%. The savings in water are more pronounced in arid areas. These experiments clearly established that such savings could be of critical importance in arid areas. Areas having elaborated irrigation do not appear to show considerable advantage. Mulching, therefore, would appear and promising for arid lands.
3. Yields of crops may not necessarily be substantially increased directly by usage of mulching, but more land can be cultivated with the available amount of water and thus overall cultivation of crops can be increased. However, it is significant to not that in both experients conducted in arid areas increased yields were reported.
4. 150-200 gauge PVC film based on normal compositions would withstand weathering for 2 seasons. However, the life of film could be increased by covering the film with the soil and thus preventing direct exposure of the film to sunlight. PVC film based on special compositions would certainly have better weather resistance and would last for several seasons. Black as well as completely opaque, white film would be better than natural semi-transparent film in respect of weather resistance. Black film would appear to be better for colder climates while opaque white film would show some advantages for warm climates.
5. Black PVC film shows better control on weed growth than completely opaque white and natural translucent film.

Limitations

- Probability of 'burning' or 'scorching' of the young pants due to high temperature of black film.
- Difficulty in application of top dressed fertilizer
- Reptile movement and rodent activities are experienced in some places.
- More runoff
- Environmental pollution
- Difficult in machinery movement
- Cannot be used for more than one season using thin mulches
- Weed penetration with thin films.

Studies on mulching at various centres of PFDC's all over India

Sl. No.	Crop	Location of PFDC	Mulch material	Increase in yield (%)	Additional income (Rs./ha)
1.	Chilli	Navasari (Gujarat)	Black plastic (50 micron)	60.1	10140.00
2.	Brinjal	Navasari (Gujarat)	Black plastic (50 micron)	27.1	7400.00
3.	Sugarcane	Navasari (Gujarat)	Black plastic (50 micron)	50.2	25000.00
4.	Chilli	Navasari (Gujarat)	Green plastic (50 micron)	59.0	22190.00
5.	Cauliflower	Hisar	Black plastic (50 micron)	31.9	6751.00
6.	Potato	Pantnagar (UP)	Black plastic (50 micron)	35.5	8700.00
7.	Cauliflower	Pantnagar (UP)	Black plastic (50 micron)	71.0	16120.00
8.	Tomato	Pantnagar (UP)	Plastic film (25 micron)	46.5	11250.00
9.	Okra	Pantnagar (UP)	Plastic film (25 micron)	47.85	9250.00
10.	Tomato	Pantnagar (UP)	Plastic film (25 micron)	79.2	22764.00
11.	Tomato	Kharagpur (WB)	Plastic film (25 micron)	65.4	43210.00
12.	Okra	Kharagpur (WB)	Plastic film (25 micron)	55.1	19625.00
13.	Guava	Delhi	Plastic film (100 micron)	26.0	--
14.	Lemon	Delhi	Plastic film (100 micron)	21.6	--
15.	Kinnow	Delhi	Plastic film (100 micron)	46.8	--
16.	Pomogranate	Delhi	Plastic film (100 micron)	33.3	
17.	Brinjal	Coimbatore	Plastic film (25 micron)	33.3	12062.00
18.	Bhendi	Coimbatore	Plastic film (25 micron)	46.7	9770.00
19.	Bhendi	Coimbatore	Plastic film (25 micron)	54.0	6400.00
20.	Chilli	Coimbatore	Plastic film (25 micron)	18.6	6800.00
21.	Groundnut	Coimbatore	Plastic film (15 micron)	20.5	7300.00
22.	Banana	Travacore (Kerala)	Plastic film (50 micron)	12.6	13906.00
23.	Arecanut	Travacore (Kerala)	Plastic film (50 micron)	28.4	--
24.	Bhendi	Travacore (Kerala)	Plastic film (50 micron)	25.0	18885.00
25.	Maize	Rajendranagar (AP)	Plastic film (25 micron)	44.6	9800.00
26.	Brinjal	Rajendranagar (AP)	Plastic film (25 micron)	10.0	15100.00
27.	Bhendi	Rajendranagar (AP)	Plastic film (25 micron)	67.0	18300.00
28.	Tomato	Rajendranagar (AP)	Plastic film (25 micron)	65.3	13800.00
29.	Plum	Solan (HP)	Plastic film (50 micron)	9.2	12000.00
30.	Tomato	Solan (HP)	Plastic film (50 micron)	85.6	18250.00
31.	Pea	Solan (HP)	Plastic film (50 micron)	66.6	25960.00
32.	Apricot	Solan (HP)	Plastic film (50 micron)	33.3	18320.00
33.	Peach	Solan (HP)		31.2	13890.00

Organic Farming as a climate change adaptation and mitigation strategy in rainfed agriculture

KA Gopinath, G Ravindra Chary, G Venkatesh, M Jayalakshmi, VS Baviskar and Ramulu
ICAR-Central Research Institute for Dryland Agriculture, Hyderabad-500 059

The practice of farming described as 'organic' is promoted under many names (Merrill, 1983). Some of the descriptive names which are, or have been, used in reference to it are: humus farming, natural farming, bio-dynamic farming, biological farming, ecological farming, holistic farming, alternative farming, sustainable farming and scientific ecological farming. In general, these names are used interchangeably, the choice being determined by personal preference as much as by the audience for whom it is used. The only real exception to the general synonymity of these names is bio-dynamic which is used by and in reference to the methods developed by the agricultural followers of Rudolf Steiner. It is perhaps of interest to note that organic, which is used fairly widely, continues to carry the heaviest load of negative connotations.

The vast majority of rainfed farmers in remote areas still practice low external input or no external input farming which is well integrated with livestock, particularly small ruminants. Based on several surveys and reports, it is estimated that up to 30% of the rainfed farmers in many remote areas of the country do not use chemical fertilizers and pesticides. Thus, many resource poor farmers are practicing organic farming by default. The Government of India task force on organic farming and several other reviewers have identified rainfed areas and regions in north-east as more suitable for organic farming in view of the low input use (GOI, 2001; Dwivedi, 2005; Ramesh *et al*., 2005). Rainfed areas are reported to have relative advantage to go for organic farming primarily due to i) low level of input use, ii) shorter conversion period and iii) smaller yield reductions compared to irrigated areas, but no one can suggest any large scale conversion in view of several limitations particularly availability of organic amendments in required quantities (Venkateswarlu, 2008). Adoption of soil and water conservation measures, a key component of rainfed farming is also one of the pillars of organic farming. Mulching or mulch cum manuring, residue management, green leaf manuring, cover cropping are other strategies that conserve moisture and improve nutrient use efficiency in drylands which are also the essential components of organic production methods. The use of FYM or other organic nutrient sources during aberrant rainfall years in particular have an additional advantage of protecting the crop from drought besides the nutritional benefits, so critical in drylands. While there is no contradiction between these established rainfed farming technologies and the objectives of the organic farming, the only issue will be the labour and capital intensive nature of some of these technologies and its ultimate impact on the cost of production.

Definition of Organic Farming

There is no single definition for organic farming as it often refers to a movement rather than to a single policy. Organic farming was defined by USDA (1980) as "….Production systems which avoid or largely exclude the use of synthetically compounded fertilizers, pesticides, growth regulators and rely upon crop rotations, crop residues, animal manures, green manures, off-farm organic wastes, mechanical cultivation, mineral bearing rocks, and aspects of biological pest control to maintain soil productivity and tilth, to supply plant nutrients, and to control insects, weeds, and other pests". Organic agriculture is defined in India's National Programme for Organic Production (NPOP) as "a system of farm design and management to create an ecosystem, which can achieve sustainable productivity without the use of artificial external inputs such as chemical fertilizers and pesticides".

Development and State of Organic Farming in India

There has been significant increase in the area under certified organic farming during the last 10 years. With less than 42,000 ha under certified organic farming during 2003-04, the area under organic farming grew by almost 25 fold, during the next 5 years, to 1.2 million ha during 2008-09. Later, however, the area under certified organic farming has fluctuated between 0.78-1.1 million ha. Presently, about 0.51 million ha area is under certified organic cultivation and India ranks 15th in terms of total land under organic cultivation and 96th position for agriculture land under organic crops to total farming area. The countries with the largest areas of organic agricultural land are Argentina, China, Uruguay, Barzil and India (in that order) (Willer and Julia, 2015). During 2013-14, India had the largest number of organic producers of about 0.65 million and accounted for 1.24 million tons of certified organic produce. India exported **135 products** during **2013-14** with the total volume of **194088 MT i**ncluding **16322 MT organic textiles**. The organic agri-export realization was around **403 million US $** including **183 US $** organic textiles registering a **7.73%** growth over the previous year.

Organic Farming and Climate Change

Agriculture is a major contributor to emissions of methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). According to the Inter-governmental Panel on Climate Change (IPCC) agriculture accounts for 10-12% of global greenhouse gas (GHG) emissions and this figure is expected to rise further. GHGs attributed to agriculture by the IPCC include emissions from soils, enteric fermentation (GHG emissions from the digestion process of ruminant animals), rice production, biomass burning and manure management (Smith *et al.*, 2007). There are other 'indirect' sources of GHG emissions that are not accounted for by the IPCC under agriculture such as those generated from land-use changes, use of fossil fuels for mechanization, transport and agro-chemical and fertilizer production (IFOAM, 2009).

Climate change and variability are a considerable threat to agricultural communities, particularly in India. This threat includes the likely increase of temperature, extreme weather conditions, increased water stress and drought, and desertification. Seasonal variations in weather events may pose risks to traditional methods of crop production either due to water constraints or surplus of water and erosion. In this regard, soil stability will become crucial to store water in the soil profile, to resist extreme weather events and minimize soil erosion. These changes will bring new challenges to farmers. Farmers need tools to help them adapt to these new conditions. Organic farming is one such option which is reported to have both climate change mitigation and adaptation potential particularly in rainfed agriculture.

Potential of organic farming to mitigate climate change

There is considerable world-wide support at present in advocating organic agriculture for mitigating climate change (Kotschi and Miiller-Samann, 2004; Niggli, 2007; IFOAM, 2008; Goh, 2011). The potential of organic agriculture in mitigating climate change depends on its ability to reduce emissions of GHGs (nitrous oxide, carbon dioxide and methane), increase soil carbon sequestration, and enhance effects of organic farming practices which favour the above two processes (Goh, 2011).

Reduction of GHG emissions

The global warming potential of conventional agriculture is strongly affected by the use of synthetic nitrogen fertilizers and by high nitrogen concentrations in soils. However, organic farming systems avoid the use of synthetic fertilizers, and rely on practices such as green manuring, crop rotation with legumes, efficient recycling of bioresidues and the use of organic manures. In addition, these systems avoid the use of synthetic pesticides and rely on practices such as crop rotations, use of bio-pesticides and increase beneficial insects for pest management. These restrictions on fossil-fuel based fertilizer and pesticide inputs can significantly reduce the overall GHG footprint of organic systems in comparison to conventional production systems (Sreejith and Sherief, 2011). Recent experimental results suggest that organic agriculture can significantly reduce GHG emissions.

Reduction of nitrous oxide emissions: N_2O emissions are the most important source of agricultural emissions: 38% of agricultural GHG emissions (Smith *et al.*, 2007). The IPCC attributes a default value of 1% to applied fertilizer nitrogen as direct N_2O emissions (Eggleston *et al.,* 2006). Similarly, emission factors of up to 3-5 kg N_2O-N per 100 kg N-input have been reported by Crutzen *et al.* (2007). These higher values for global N_2O budget are due to the consideration of both direct and indirect emissions, including also livestock production, NH_3 and NO_3 emissions, nitrogen leakage into rivers and coastal zones, etc (Scialabba and Muller-Lindenlauf, 2010). Nitrous oxide emissions are directly linked to the concentration of available mineral N (ammonium and nitrate) in soils arising from the nitrification and denitrification of available soil and added fertilizer N (Firestone and Davidson, 1989; Wrage *et al.,* 2001). High emissions rates are detected directly after mineral fertilizer additions and are very variable (Bouwman, 1995).

In organic systems, the nitrogen input to soils, and hence the potential nitrous oxide emissions, are reduced. The share of reactive nitrogen that is emitted as N_2O depends on a broad range of soil and weather conditions and management practices, which could partly foil the positive effect of lower nitrogen levels in top soil (Scialabba and Muller-Lindenlauf, 2010). One study found no significant differences between mineral and organic fertilization (Dambreville *et al.,* 2007). In a study by Petersen *et al.* (2006), lower emission rates for organic compared to conventional farming were found for five European countries. In a long-term study in southern Germany, Flessa *et al.* (2002) also found reduced nitrous oxide emission rates in the organic farm, although yield-related emissions were not reduced.

Reduction of methane emissions: The reduction or avoidance of CH_4 emissions is of special importance in global warming from the agricultural sector because two thirds of global CH_4

emissions are of anthropogenic origin, mainly from enteric ruminant fermentation in animals (FAO, 2006) and in paddy rice production (Smith and Conan, 2004). In general, the CH_4 emissions from ruminants and rice production are not significantly different between organic and conventional agriculture. Differences are due largely to the extent and intensity of various farming practices and their improvement used within different forms of agriculture.

Although research on CH_4 emissions in organic and conventional paddy rice production is still in its infancy (Goh, 2011), employing better rice production techniques such as using low CH_4-emitting varieties (Yagi *et al.,* 1997; Aulakh *et al.,* 2001), composted manures with low C/N ratio (Singh *et al.,* 2003), adjusting the timing of organic residue additions (Xu *et al.,* 2000; Cai and Xu, 2004) and using mid-season drainage or avoiding continuous flooding have been shown to reduce CH_4 emissions (Smith and Conan, 2004). Further, as herbicides are not used in organic systems, aquatic weeds tend to be present in organic rice paddies and weeds have an additional decreasing effect on methane emissions (Inubushi *et al.*, 2001). In organic farming systems, cropping depends on nutrient supply from livestock and the combination of cropping and livestock provides an efficient means of mitigating GHG emissions especially CH_4 (Goh, 2011). Efficient and direct recycling of manure and slurry is the best option to reduce GHG emissions as this practice avoids long-distance transport (Niggli, 2007).

Methane and N_2O from manure account for about 7% of the agricultural GHG emissions. Methane emissions predominantly occur in liquid manure systems, while N_2O emissions are higher in solid manure systems and on pastures (Smith *et al.*, 2007). There is a very high variance for both gaseous emissions, depending on composition, coverage, temperature and moisture of the manure. Storing manure in solid form such as composting can suppress CH_4 emissions but may result in more N_2O emissions (Paustian *et al.*, 2004).

Reduction of carbon dioxide emissions: Synthetic external inputs like fertilizers and pesticides are banned in organic farming. The energy used for the chemical synthesis of nitrogen fertilizers, which are totally excluded in organic systems, represent up to 0.4–0.6 Gt CO_2 emissions (EFMA, 2005; Williams *et al*., 2006; FAOSTAT, 2009). This is as much as 10% of direct global agricultural emissions and around 1% of total anthropogenic GHG emissions. Further, CH_4 and N_2O from biomass burning account for 12% of the agricultural GHG emissions. Additionally, the carbon sequestered in the burned biomass is lost to the atmosphere. In organic agriculture, preparation of land by burning vegetation is restricted to a minimum (IFOAM, 2002). CO2-e emissions are reported to be around 40-60% lower in organic farming systems than conventional systems, largely because they don't use synthetic nitrogen fertilizers which require large amounts of energy in their production and are associated with emissions of the powerful GHG nitrous oxide (Sayre, 2003, BFA 2007).

Soil carbon sequestration

Soil C sequestration is an important strategy and is a win–win option of producing more food per unit area besides mitigation of climate change (Lal, 2004). Although soils of the tropical regions have low C sequestration rate because of high temperatures, adoption of appropriate management practices can lead to higher rates particularly in high rainfall regions (Srinivasarao *et al*., 2012). Soil carbon sequestration at a global scale is considered the mechanism responsible for the greatest mitigation potential within the agricultural sector, with an estimated 90% contribution to the potential of what is technically feasible (Smith *et al*., 2007, 2008). Thus, improved agronomic practices that could lead to reduced carbon losses or even increased soil carbon storage are highly desired (Gattinger *et al*., 2012).

Soil carbon sequestration is enhanced through agricultural management practices (such as increased application of organic manures, use of intercrops and green manures, higher shares of perennial grasslands and trees or hedges, etc.), which promote greater soil organic matter (and thus soil organic carbon) content and improve soil structure (Niggli *et al*., 2008; Muller, 2009). There is strong scientific evidence that organic farming generally results in higher soil carbon levels in cultivated soils compared to chemical fertilizer based agriculture. Similarly, several field studies have proved the positive effect of organic farming practices on soil carbon pools (Pimentel *et al*., 2005; Fliessbach *et al.*, 2007; Kustermann *et al*., 2008). Gattinger *et al*. (2012) subjected datasets from 74 studies from pair-wise comparisons of organic vs. nonorganic farming systems to metaanalysis to identify differences in soil organic carbon (SOC). The analysis revealed significant differences and higher values for organically farmed soils of 0.18±0.06% points (mean±95% confidence interval) for SOC concentrations, 3.50±1.08 Mg C/ha for stocks, and 0.45±0.21 Mg C/ha/year for sequestration rates compared with nonorganic management. Leifeld and Fuhrer (2010) found in their review an average annual increase of the SOC concentration in organic systems by 2.2%, whereas in conventional systems, SOC did not change significantly.

Organic agriculture as an adaptation strategy

Adaptation in agriculture is not new. Historically, farmers have developed several methods to adapt to changing climate including aberrant weather. However, the adaptation needs to occur at a much faster rate due to impending climate change. The Intergovernmental Panel on Climate Change (IPPC) defines adaptation to climate change as ‘adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2001). Long-term crop yield stability and the ability to buffer yields through climatic adversity are critical factors in agriculture's ability to support society in the future (Lotter *et al*., 2003). Several researchers have reported that organic farming systems perform better than their conventional counterparts during climate extremes including drought and excessive rainfall.

Several mechanisms may increase drought tolerance of organic cropping systems. Soil organic matter has positive effects on the water-capturing capacity of the soil. Numerous studies have shown soil organic carbon to be higher in organically managed systems (Reganold, 1995; Clark *et al*., 1998; Liebig and Doran, 1999; Gopinath *et al*., 2008, 2011). As a result, organically managed soils have high water holding capacity (Liebig and Doran, 1999; Wells *et al*., 2000). It was found that water capture in organic plots was twice as high as in conventional plots during torrential rains (Lotter *et al*., 2003). Similarly, Pimentel *et al*. (2005) reported that the amount of water percolating through the top 36 cm was 15-20% greater in the organic systems of the Rodale farming systems trial compared to conventional systems. In India, most of the organic cotton farmers stated that the capacity of their soils to absorb and retain water was increased after conversion to organic management (Eyhorn *et al*., 2009). Many farmers also said that they need less rounds of irrigation and the crops can sustain longer periods of drought. In the 21-year Rodale Farming Systems Trial, in which two organic and a conventional crop rotation were compared, the organic crop systems performed significantly better in 4 out of 5 years of moderate drought. In the severe drought year of 1999, three out of the four crop comparisons resulted in significantly better yields in the organic systems than the conventional (Lotter *et al*., 2003).

The mitigation of runoff, erosion and crop losses as a result of rainfall excess is also improved in organically managed systems (Lotter *et al*., 2003). Organic management of soils leads to improved soil stability and resistance to water erosion compared to conventionally managed soils, due to higher soil C content and improved soil aggregation (Reganold, 1995; Clark *et al*., 1998; Liebig and Doran, 1999), permeability (Reganold *et al*., 2001) and lower bulk density as well as higher resistance to wind erosion (Jaenicke, 1998). Hence, organic crop management techniques will be a valuable resource in an era of climatic variability, providing soil and crop characteristics that can better buffer environmental extremes (Lotter *et al*., 2003).

Conclusion

Organic agricultural systems have an inherent potential to both mitigate climate change through reduced GHG emissions and higher carbon sequestration in the soil, and adapt to climate change. Farming practices such as organic agriculture that preserve soil fertility and maintain or even increase organic matter in soils are in a good position to maintain productivity in the event of drought, irregular rainfall events with floods, and rising temperatures. Soils in organic agriculture capture and store more water than soils of conventional cultivation. Therefore, organic agriculture is one of the adaptation strategies that can be targeted at improving the livelihoods of rural populations that are especially vulnerable to the adverse effects of climate change and variability.

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Rainwater Management for Mitigation of Droughts

K.S.Reddy, Prinicipal Scientist (S&WCE) ,
Central Research Institute for Dryland Agriculture, Hyderabad

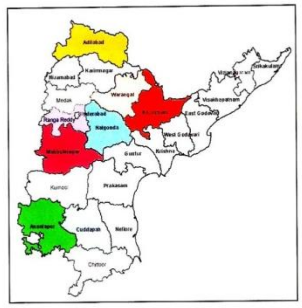
ABSTRACT

National Agricultural Innovation Project (NAIP) Component 3 sub project on "Sustainable Rural Livelihoods through Enhanced Farming Systems Productivity and Efficient Support Systems in Rainfed Areas" has employed many engineering interventions for enhancing the systems productivity and thereby improving the livelihoods of the rural poor. The paper illustrates cases of successful resource conservation interventions that provide employment opportunities during their implementation and revitalize rainfed agriculture through sustainability and cropping intensity enhancement. These interventions include rainwater harvesting and reuse, water resource development/augmentation, demand management of water at micro level in the predominantly rainfed areas of Andhra Pradesh. The project has followed a participatory action research framework and used community mobilization techniques for sensitizing the rural poor about resource conservation. Finally, it demonstrates how a well designed and implemented intervention could have a significant impact on the capacity of the rural community to conserve and use precious resource like rainwater.

Introduction

The National Agricultural Innovation Project (NAIP) deals with research on sustainable rural livelihoods under its component 3. One of the sub projects of component 3 titled "Sustainable Rural Livelihoods Through Enhanced Farming Systems Productivity and Efficient Support Systems in Rainfed Areas" is being implemented across 8 districts of Andhra Pradesh (see map) with a view to improving the livelihoods of the rural poor by adopting strategies of sustainable natural resource management, productivity and profitability enhancement, building support systems and institutions, and converging on development agenda of different development agencies. In other words, it is aimed at testing a new model of sustainable rural livelihood (SRL) strategy, which is focused on innovations in ***technology transfer, support systems*** and ***collective action*** with the overall goal of improving the ***income*** and ***livelihoods*** of people. The SRL strategy is considered most relevant to the target area as it is only through the improvement of **farming systems productivity** and **enabling institutions** in most disadvantaged areas the goal of poverty reduction can be achieved.

The project is conceived with the overall objective of addressing rural livelihoods holistically by piloting innovations to optimize the use of **natural** and **human capitals** and by building institutional capability to sustain the gains through convergence of expertise at watershed/cluster level.



Location and Project Sites

One of the major strategies for improving rural livelihoods on a sustainable basis is through enhancing the overall systems productivity which aims at improving the capacity of harvesting and utilizing rainwater at the community level. This strategy involves measures that aim at scientifically designing and executing rainwater harvesting structures. Besides, interventions that promote improving water productivity and timeliness of agricultural operation are also pursued as part of the productivity enhancement strategy. The following cases explain how specific engineering interventions made an impact on augmenting rainwater availability and thus increasing systems productivity.

Case 1: Rainwater harvesting through farm ponds: Emphasis on topo survey and runoff analysis

Water is most crucial resource for sustainable agricultural production in the dry land/rain fed areas. However, the major part of the rainwater goes away unused as runoff washing away precious top soil. Recent analysis of the rainfall pattern shows that there is an increase in the number of high intensity rainfall followed by long spells of drought. This calls for taking measures to harvest the excess runoff during the high rainfall events and reuse the same for life saving irrigation during drought spells. A location specific rainwater harvesting method through farm ponds was standardized to address this problem. Besides, the project has evolved a process for up-scaling this technology in convergence with on-going programmes like NREGS.

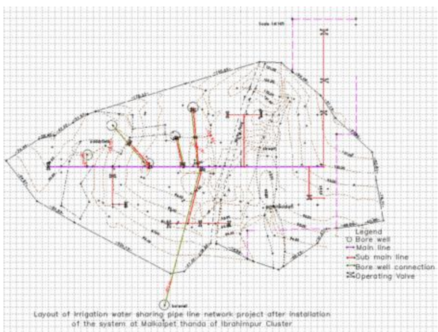
The Seethatgondi cluster of Adilabad district is predominantly populated with tribals who are engaged in subsistence agriculture despite receiving an average rainfall of 1050 mm annually and fairly deep black soils. The topography here has good potential for harvesting runoff. Considering the slopes of the fields, an appropriate location was identified after a detailed topo survey of the location for a dug out pond (17m x 17 m x 4.5 m) involving a group of farmers as stakeholders. By highlighting the benefits of the proposed intervention, the farmers were persuaded and agreed to get the Farm Pond dug in their land. Soon after the farm pond was dug (July, 2008), there were good rains leading to complete filling. The rainwater filled to the brim of the pond got the farmers enthused.

They hired diesel engine to irrigate half acre area where they grew tomatoes. Overwhelmed by this response, the NAIP project has facilitated inclusion of digging work in the NREGS shelf of works. Consequently the district authorities of Adilabad had visited this successful farm module and have allocated an amount of Rs.20.00 lakhs for up scaling this intervention. This intervention, while creating the employment under NREGS, facilitated for intensive cultivation of crops/vegetables and to overcome the intermittent dry spells with supplemental irrigation.

Farm pond dug under NREGS being widened and deepened

Case 2: Sustainable use of groundwater: Pipeline networking and social engineering for participatory management

Cultivation of rice using precious groundwater is a common practice in the rainfed areas of Andhra Pradesh. Malkaipet thanda in Ibrahimpur cluster, Rangareddy district, one of the driest regions of Andhra Pradesh, is not an exception to the practice. This area has been categorized as "over exploited" in terms of groundwater resources. NAIP staff, keeping this in view started working on promoting better water management through a water sharing arrangement among farmers. The efforts in this direction were initiated by WASSAN, the cluster anchoring partner in the Ibrahimpur cluster, Rangareddy district as soon as the project began. It involved a series of consultations with the bore well owning farmers and the neighbouring ones who did not have water source to irrigate their lands. Initially, the two tube well owning farmers did not like the idea. The project then got a defunct bore well repaired as an incentive and again approached the farmers who had mellowed down by then and agreed to share water, provided the project assisted the community for digging a few more bore wells so that there was enough water to share it across a large area. This time, the project contacted NABARD for assistance who came forward with financing the digging of two tube wells in that area under their Comprehensive Land Development Programme (CLDP). This raised the hopes of several farmers including those who owned bore wells initially, because with the pooling of water, they could now irrigate other patches of their dry lands where they could not have provided water. Thus, the one year long negotiations with the community to implement social regulation for groundwater usage finally yielded results. Over 60 acres of land belonging to 18 households was brought under protective irrigation by laying out a network of pipelines and bore wells at Malkaipet thanda in Ibrahimpur cluster, Rangareddy district. The entire group of farmers has agreed not to cultivate rabi paddy but to share bore water among themselves for growing ID crops. For the first time an area of 25 acres came under groundnut with protective irrigation during rabi 2009 where no second crop was possible earlier. **Groundnut was generally cultivated in kharif with an average yield of 400 kg/acre. With this intervention, groundnut could also be cultivated in rabi with much higher yield level (550 kg/acre).** This intervention helped increase cropping intensity besides creating additional employment, income for the farm families. Next year, the area under protective irrigation through the pipeline networking will increase to its full potential i.e. 18 ha.

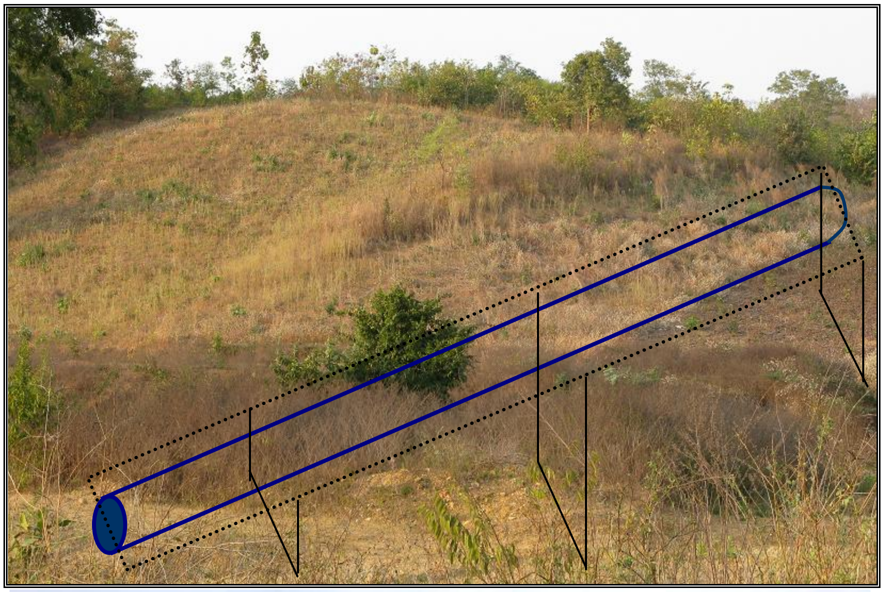


Case 3: Enabling farmers for augmenting water availability

Bheemavaram tank in Tummalacheruvu cluster (Khammam) serves as a source of irrigation for about 120 acres. However, the command area is divided into two parts by a drainage channel flowing across the area. As a result, the entire command area did not get the benefit of irrigation by the tank. Therefore, the farming community had been desiring for long for construction of an aqueduct across the drainage channel so that irrigation water could be transported from one side the command area to other side. But it did not materialize due to local problems. In the absence of such an arrangement, half of the designed command area remained un-irrigated.

However, the excess water that flows out of the tank every year during the rainy season goes waste since it flows down into a drain without becoming accessible to the fields on the other side of the command. Therefore, one of the first demands of the community when the project team interacted with them through PRA was construction of aqueduct across the *Bandlavaagu* drain. In order to make this dream come true, project team along with a group of consulting engineers took up the issue.

The group after careful study, recommended for construction of an aqueduct across the stream and discussed with the farmers if they could take the responsibility of laying the aqueduct under the guidance of project staff and engineers. Since the area is very remote and generally no contractor would take up work in such a hinterland, the farmers agreed to lay the aqueduct on their own. The farmers were encouraged to formulate a user group and open a joint account in the bank so that financial assistance could be directly delivered to the group without much delay. The farmers contributed labour and a committee of the user group and project staff monitored the construction of aqueduct under the guidance of engineers. The construction employed latest low cost technology involving continuous HDPE pipes supported by steel columns instead of cement pipes and RCC columns which brought down the cost almost by 40%. The farmers are very happy with their dream coming true and are working to dig distribution channels downstream so that the entire potential of the overflowing water could be harnessed to irrigate about 120 acres.



Schematic diagram of the aqueduct before (above); aqueduct after completion

The table below illustrates the rainwater harvesting and storage potential of various interventions and the resultant increase in protective irrigation potential, cropping intensity apart from additional income that could be generated in one season.

Table 1: Impact of Interventions Aimed at Rainwater Harvesting and Use

Cluster	**RWH and use strategy**	**Rainwater storage capacity created (cu m)**	**Man days gene-rated**	**Protective irrigation potential created (acre)**	**Increase in cropping intensity (%)**	**Additional income Potential per season (Rs)**
Seethagondi, Adilabad	Farm ponds	3238	600	7.0	200	84010
Pampanur, Anantapur	Farm ponds Percolation ponds	3611	1938	7.8	150	31200
B.Y.Gudi,	Contour Bunding	425	380	NA	NA	NA

Kadapa						
Thummala-cheruvu, Khammam	Aqueduct	NA	50	120	150	720000
Jamisthapur, Mahbubnagar	Farm ponds, check dams and Percolation ponds	4850	1378	10.5	150	41945
Dupahad, Nalgonda	Tank deepening and de-silting	3695	2500	8.0	200	95867
Ibrahimpur, Rangareddy	Networking of bore wells with social regulation	NA	500	45	250	630000
Jaffergudem, Warangal	Farm ponds, percolation ponds,	5100	3700	11	150	66160
	Total	**21419**	**11046**	**209.3**	178.5*	**16,69,182**

**Average cropping intensity*

Conclusion

Engineering interventions have a very significant role in the areas of resource conservation, value addition and promotion of mechanization for timely agricultural operations. The mechanization needs of rainfed agriculture vary widely depending on the local needs, resources and cropping pattern. Engineering interventions can have remarkable impact on improving the livelihoods of the rural poor, as they are shown to improve yield levels by 15% and reduce costs up to 30% besides improving timeliness of operations. Therefore, there is a strong need to consider a carefully thought out strategy involving need based engineering interventions in any productivity enhancement programme. However, these need to be taken up in participatory mode by involving the community so that they have a long lasting impact. Other stakeholders like rural artisans, entrepreneurs need to be involved in building a support system for promoting mechanization at village level. Further, a constant capacity building initiative must go hand-in-hand. This can be achieved by involving the community right from the planning stage. This will inculcate a sense of ownership by the community resulting into sustainable improvement of rural livelihoods.

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Elevated CO_2 in alleviating drought stress of rainfed crops

M. Vanaja, Principal Scientist
Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad-500059

The changes in the composition of atmosphere in terms of greenhouse gases, aerosols influence the properties of solar radiation and alter the energy balance of the climate system. Now it is evident from various studies that the human activities are contributing significantly for the change in climate compared to natural variability in climate. General circulation models predict temperature rises of 1.4-5.8°C by 2100, associated with carbon dioxide increases to 540-970 parts per million. The atmospheric concentration of carbon dioxide- the most important anthropogenic greenhouse gas increasing at alarming rates (1.9 ppm per year) in recent years than the natural range concentration growth rate. This could be due to enhanced usage of fossil fuel and changed land use pattern to some extent.

Agriculture is sensitive to climate change at the same time it is one of the major driver for climate change. Understanding the weather variables over a period of time and setting the management practices for better harvest is required for the growth of agricultural sector as a whole as climate change impact on agriculture is the major deciding factor for the survival of mankind on the earth. Of the 1.5 billion hectares (ha) of cropland worldwide, only 18% (277 million hectare) is irrigated land; the remaining 82% is rainfed land. The importance of rainfed agriculture varies regionally, and is most significant in country like India where rainfed agriculture accounts for about 65% of the cropland and 70% of population main occupation. Under current water use practices, increases in population and changes in diet are projected to increase water consumption in food and fiber production by 70-90%. If demands for biomass energy increase, this may aggravate the problem. In addition, sectoral competition for water resources will intensify, further exacerbating the stress on developing country producers. Throughout the 20th century, global water use has increased in the agricultural, domestic and industrial sectors. Projections indicate that both global water use and evaporation will continue to increase.

The carbon dioxide level in the atmosphere has been rising, and that this rise is due primarily to the burning of fossil fuels and to deforestation. Measured in terms of volume, there were about 280 parts of CO_2 in every million parts of air at the beginning of the Industrial Revolution, and there are 395 parts per million (ppm) today, more than 30 percent rise. The annual increase is 1.9 ppm, and if present trends continue, the concentration of CO_2 in the atmosphere will double to about 700 ppm in the latter half of the 21st century.

Carbon dioxide is the basic raw material that plants use in photosynthesis to convert solar energy into food, fiber, and other forms of biomass. In the presence of chlorophyll, plants use sunlight to convert carbon dioxide and water into carbohydrates that, directly or indirectly, supply almost all animal and human needs for food; oxygen and some water are released as by-products of this process. Voluminous scientific evidence shows that if CO_2 were to rise above its current ambient level of 395 parts per million, most plants would grow faster and larger because of more efficient photosynthesis and a reduction in water loss. There are two important reasons for this productivity boost at higher CO_2 levels. One is superior efficiency of photosynthesis and the other is a sharp reduction in water loss per unit of leaf area. A related benefit comes from the partial closing of pores in leaves that is associated with higher CO_2 levels. These pores, known as stomata, admit air into the leaf for photosynthesis, but they are also a major source of transpiration or moisture loss. By partially closing these pores, higher CO_2 levels greatly reduce the plants' water loss- a significant benefit in arid and semi arid climates where water is limiting the productivity.

There are marked variations in response to CO_2 among plant species. The biggest differences are among three broad categories of plants- C3, C4, and Crassulacean Acid Metabolism or CAM- each with a different pathway for photosynthetic fixation of carbon dioxide. Most green plants, including most major food crops use the C3 pathway respond most dramatically to higher levels of CO_2. At current atmospheric levels of CO_2, up to half of the photosynthates in C3 plants is typically lost and returned to the air by a process called photo-respiration, Elevated levels of atmospheric CO_2 virtually eliminate photo-respiration in C3 plants, making photosynthesis much more efficient.

Corn, sugarcane, sorghum, millet, and some tropical grasses use the C4 pathway, also experience a boost in photosynthetic efficiency in response to higher carbon dioxide levels, but because there is little photo-respiration in C4 plants, the improvement is smaller than in C3 plants. Instead, the largest benefit C4 plants receive from higher CO2 levels comes from reduced water loss. Loss of water through leaf pores declines by about 33 percent in C4 plants with a doubling of the CO_2 concentration from its current atmospheric level. Since these crops are frequently grown under drought conditions of high temperatures and limited soil moisture, this superior efficiency in water use may improve yields when rainfall is even lower than normal. When there was no stress, elevated CO_2 reduced stomatal conductance by 21.3 and 16.0% for C_3 and C_4 species respectively. The lowest response to higher CO_2 levels is usually from the CAM plants, which include pineapples, agaves, and many cacti and other succulents. CAM plants are also already well adapted for efficient water use.

The mean (average) response to a doubling of the CO_2 concentration from its current level of 395 ppm is a 30 percent improvement in plant productivity, with varied manifestations in different species. In crop plants, a distinction has to be made between the increase in total biomass and increase in economic yield resulting from an elevated CO_2 supply. When the dry mass production and yield increase of the world's ten most important crop species in response to elevated CO_2 was analyzed from different experiments, it was found that in some species the relative increase of total biomass and in others that of economic yield is greater. Cereal grains with C3 metabolism, including rice, wheat, barley, oats, and rye, show yield increases ranging from 25 to 64 percent, resulting from a rise in carbon fixation and reduction in photo-respiration. Food crops with C4 metabolism, including corn, sorghum, millet, and sugarcane, show yield increases ranging from 10 to 55 percent, resulting primarily from superior efficiency in water use. Tuber and root crops, including potatoes and sweet potatoes, show dramatic increase in tuberization (potatoes) and growth of roots (sweet potatoes). Yield increases range from 18 to 75 percent. Legumes, including peas, beans, and soybeans, show yield increases of 28 to 46 percent.

Field crops under drought often experience two quite different but related and simultaneous stresses: soil water deficit and high temperature stresses. Elevated CO_2 increase growth, grain yield and canopy photosynthesis while reducing evapotranspiration. During drought stress cycles, this water savings under elevated CO_2 allow photosynthesis to continue for few more days compared with the ambient CO_2 so that increase drought avoidance. Elevated atmospheric CO_2 concentration ameliorates, to various degrees, the negative impacts of soil water deficit and high temperature stresses.

Impact on root biomass- C sequestration

Increased CO_2 concentration in the atmosphere has been shown to enhance plant biomass and increases C sequestration. As a result, terrestrial ecosystems in a higher CO_2 environment will likely become greater C sinks and thus mitigate CO_2 increase in the atmosphere. The effectiveness of mitigation, however, is determined by the magnitude of biomass enhancement at elevated CO_2 and the permanence of sequestered C, i.e., the length of time atmospheric C is sequestered in the biosphere. The permanence of sequestered C depends on, among other factors, the allocation of biomass between shoots and roots because above- and below-ground C are exposed to vastly different temperature and moisture, which are key factors determining the rate of biomass decomposition, an important pathway for biospheres' C to re-enter the atmosphere. Because plant roots are the primary organs for absorbing nutrients and water from the soil, biomass partitioned to roots also has important implications for the dynamics of nutrient and water cycling, which are intimately related to C cycling in terrestrial ecosystems. Various biotic and abiotic factors have been demonstrated to affect the relative growth of shoots and roots and hence partitioning of photosynthates to these two compartments. The most important biotic factors are the innate patterns of C allocation of the plant species and degree of competitiveness in the environment, while abiotic factors that affect C allocation include resource availability and environmental stresses. Plant shoots and roots, although complementary and interdependent, do not respond to environmental changes at the same rate or by the same magnitude. Among the many global changes projected for the future, the most prominent and best documented is the gradual but steady rise of CO_2 concentration in the atmosphere. There have been a number of recent literature reviews that have assessed the effects of elevated CO_2 on biomass allocation between above- and below-ground components. Lower soil water increased biomass allocation belowground by a greater amount at elevated than at ambient CO_2.

Impact on availability of soil moisture

Water is considered the primary factor limiting growth and productivity, and therefore the interaction between elevated CO_2 and soil water is an important issue. It has been predicted that the increasing atmospheric CO_2 may cause global warming as well as changes in precipitation patterns, drought occurrence will be more frequent, intense and erratic and will possibly affect regions not currently subjected to drought. CO_2-induced global warming has long been predicted to increase evapotranspiration, causing decreases in soil moisture that may offset concomitant increases in precipitation and lead to greater aridity in water-limited ecosystems around the world. Many studies have shown that plants grown in elevated CO_2 conditions may utilize less water, use it more efficiently and be able to tolerate drought better. Hence, soil water depletion in the root zone might occur at lower rate than for plants growing under ambient CO_2 concentrations. The reduction of stomatal conductance and therefore transpiration, and the enhancement of carbon assimilation by elevated CO_2, increases instantaneous and whole plant water use efficiency under both irrigated and drought stress. During the period of drought, elevated CO_2 was reported that it delayed by 3–4 days the depletion of soil water content. This slower rate of soil drying was in accordance with the lower rates of transpiration in plants grown under CO_2 enrichment, even though the leaf area per plant was greater than in plants grown at ambient CO_2. This water conservation could be sufficient to extend the period of photosynthesis and growth when water becomes limited. At the leaf level, in well-watered conditions, plant growth responses to CO_2 are mediated by a change in net photosynthesis, when moisture is limited, leaves at elevated CO_2 have the additional advantage of reduced stomatal conductance so that each unit of dry matter costs less water to produce. As a result, the relative effect of CO_2 is likely to be greater when moisture is limited. The field studies with high temperature and elevated CO_2 also revealed that extra CO_2 reduced the mean daily evapotranspiration rate by 19%, in spite of the fact that 20-40% increases in leaf area index were recorded in the CO_2-enriched treatments relative to the ambient-air condition. Thus, it has been proposed that elevated CO_2 ameliorates, mitigates or compensates for the negative impact of drought and high temperature on plant growth and enables plants to remain turgid and functional for a longer period.

Impact on soil microbial activity

Virtually all land plants have well-established symbioses with a large variety of microorganisms, some of which are known to support plant growth and to increase plant tolerance to biotic and abiotic stresses. Many of these microorganisms colonize the rhizosphere, while others enter the root system of their hosts and enhance their beneficial effects with an endophytic lifestyle. Abiotic stresses and enhanced CO_2 condition impact the performance of plant growth-promoting fungi such as arbuscular mycorrhizae, ectomycorrhizae and other endophytic fungi, as well as plant growth-promoting bacteria especially the more specialized plant growth-promoting *rhizo*bacteria. Many members of these categories are applied as biocontrol agents, biofertilizers and/or phyto-stimulators in agriculture or as degrading microorganisms in phyto-remediation applications. The studies showed that elevated CO_2 had a positive influence on the abundance of arbuscular and ectomycorrhizal fungi and it was observed that the effects on plant growth-promoting bacteria and endophytic fungi were more variable. Nevertheless, in most cases, plant-associated microorganisms had a beneficial effect on plants under elevated CO_2. Various field and controlled studies indicated that plant growth-promoting microorganisms both bacteria and fungi positively affected plants subjected to drought stress. Temperature effects, on beneficial plant-associated microorganisms were more variable, positive and neutral, and that negative effects were equally common and varied considerably with the system and the temperature range. With continued atmospheric CO_2 enrichment, plant growth-promoting microorganisms are expected to benefit the plants even at high temperature conditions.

Atmospheric CO_2 enrichment typically has but a small effect on the decomposition rates of senesced plant materials present in soils, yet this fact often leads to significantly greater soil carbon sequestration. It was observed that a 4% reduction in the decomposition rate of leaf litter beneath stands of 30-year-old Mediterranean forest species enriched with air of 710 ppm CO_2, however not impacted with annual crops such as soybean and sorghum plant residues. It can be concluded that the possibility exists for increased soil C storage under field crops in an elevated CO_2 due to the greater residue production resulting from CO_2-enhanced plant growth. Increase in atmospheric CO_2 concentration increased aboveground growth by 146%, while it increased the pumping of newly-fixed carbon into the soil of the CO_2-enriched plots by approximately 50%. The root decomposition in the CO_2-enriched plots was found to be 24% less than in the ambient-treatment plots indicating that both greater plant material input through higher yields and reduced residue decomposition rates under elevated CO_2 would be expected to impact soil carbon storage significantly.

Impact on soil structure

Warmer atmospheric temperatures associated with greenhouse warming are expected to lead to a more variable hydrological cycle, including more extreme rainfall events and this change is expected to influence the erosive power or erosivity of rainfall and hence soil erosion rates. With gradually increasing atmospheric CO_2 concentrations gradually enhancing plant water use efficiencies, more plants should have gradually been spreading over the surface of the land, reducing rates of surface runoff and allowing more water to infiltrate the soil, thereby providing more water to be extracted from the soil by more plants for subsequent transpiration. The enhanced aboveground crop growth under elevated CO_2, leading to more soil surface residue and greater percent ground cover coupled with positive shifts in crop root systems may have the potential to alter soil structural characteristics. In a field experiment with sorghum and soybean, the researchers observed that doubling of atmospheric CO_2 concentrations had no effect on soil bulk density and soil saturated hydraulic conductivity in the sorghum plot, but lowered by approximately 5% and 42% respectively in the soybean plot after five years. While it increased soil aggregate stability in both plots, and increased total soil carbon content by 16% in the sorghum plot and 29% in the soybean plot indicating potential impact on improvements in soil carbon storage, water infiltration and soil water retention, and reduced erosion, which valuable positive consequences as CO_2-induced benefits.

Soil Quality Management Techniques for Higher Productivity Amidst Climate Change

K.L. Sharma
Principal Scientist and National Fellow (ICAR)
Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad
klsharma@crida.ernet.in

Introduction

India is predominantly a rainfed country. Of the total geographical area of 329 million ha, 142 million ha is devoted to agriculture (FAI, 1990). Out of an estimated net cultivated area of about 142.2 m ha, only about 59 m ha is under irrigation, while 83 m ha is unirrigated. The irrigated area produces about 56% of total food requirement of India. The remaining 44% of the total food production is supported by rainfed agriculture. Most of the essential commodities such as coarse cereals (90%), pulses (87%), and oil seeds (74%) are produced from the rainfed agriculture. These statistics emphasise the role that rainfed regions play in ensuring food for the ever-rising population. Owing to diversity in rainfall pattern, temperature, parent material, vegetation and relief or topography, this country is bestowed with different soil types predominantly alluvial soils, black soil, red soils, laterites, desert soils, mountainous soils etc. Taxonomically, soils in India fall under Entisols (80.1 m ha), Inceptisols (95.8 m ha), Vertisols (26.3 m ha), Aridisols (14.6), Mollisols (8.0 m ha), Ultisols (0.8 m ha), Alfisols (79.7 m ha), Oxisols (0.3 m ha) and non-classified soil (23.1 m ha). Rainfall wise, 15 m ha area falls in a rainfall zone of <500mm, 15 m ha under 500 to 750 mm, 42 m ha under 750 to 1150 mm and 25 m ha under > 1150 mm rainfall. Predominant soil orders which represent semi-arid tropical region are Alfisols, Entisols, Vertisols and associated soils. Other soil orders such as Oxisols, Inceptisols and Aridisols also form a considerable part of rainfed agriculture. Most of the soils in rainfed regions are at the verge of degradation with low cropping intensity, relatively low organic matter status, poor soil physical health, low fertility, etc.

Out of the 328.7 m ha of land, it has been estimated that about 187.7 m ha (57.1%) of total geographical area is degraded. Of the total degraded area, water erosion has affected 148.9 m ha (45.3%), wind erosion 13.5 m ha (4.1%), chemical deterioration 13.8 m ha (4.2%), physical deterioration 11.6 m ha (3.5%). Another 18.2 m ha (5.5%) land which is constrained by ice caps, salt flats, arid mountains, and rock out crops is not fit for agriculture at all (Sehgal and Abrol, 1994). Moisture stress accompanied by other soil related constraints result in low productivity of majority of the crops (Sharma et al 1999). Besides natural causes, agricultural use of land is causing serious soil losses in many places across the world including in Indian subcontinent. It is probable that human race will not be able to feed the growing population, if this loss of fertile soils continues at the existing rate. In many developing countries, hunger is compelling the community to cultivate land that is unsuitable for agriculture and which can only be converted to agricultural use through enormous efforts and costs, such as those involved in the construction of terraces and other surface treatments.

Indian sub-continent predominantly represents wide spectrum of climate ranging from arid to semi arid, sub humid and humid with wider variation in rainfall amount and pattern. Seasonal temperature fluctuations are also vast. Soils representing rainfed regions are marginally low in organic matter status. The first predominant cause of soil degradation in rainfed regions undoubtedly is water erosion. The process of erosion sweeps away the topsoil along with organic matter and exposes the subsurface horizons. The second major indirect cause of degradation is loss of organic matter by virtue of temperature mediated fast decomposition of organic matter and robbing away of its fertility. Above all, the several other farming practices such as reckless tillage methods, harvest of every small component of biological produce and virtually no return of any plant residue back to the soil, burning of the existing residue in the field itself for preparation of clean seed bed, open grazing etc aggravate the process of soil degradation.

Predominant causes of soil degradation

The predominant reasons which degrade soil quality and deteriorate its productive capacity could be enumerated as: 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 and domestic fuel, viii) no or low green manuring as it competes with the regular crop for date of sowing and other resources, ix) poor nutrient use efficiency attributing to nutrient losses due to leaching, volatilization and denitrification, x) indiscriminate use of other agricultural inputs such as herbicides, pesticides, fungicides, etc., resulting in poor soil and water quality, xi) water logging, salinity and alkalinity and acid soils. As a result of several above-mentioned reasons, soils encounter diversity of constraints broadly on account of physical, chemical and biological soil health and ultimately end up with poor functional capacity (Sharma et al., 2007). In order to restore the quality of degraded soils and to prevent them from some further degradation, it is of paramount importance to focus on conservation agriculture practices on long-term basis.

There is no doubt that, agricultural management practices such as crop rotations, inclusion of legumes in cropping systems, addition of animal based manures, adoption of soil water conservation practices, various permutations and combinations of deep and shallow tillage, mulching of soils with in-situ grown and externally brought plant and leafy materials always remained the part and parcel of agriculture in India. Despite all these efforts, the concept of conservation farming could not be followed in an integrated manner to expect greater impact in terms of protecting the soil resource from degradative processes.

Climate related risks in Agriculture in India

According to Rao et al (2010), the major weather related risks in Agriculture could be as follows: Monsoons in India exhibits substantial inter-seasonal variations, associated with a variety of phenomena such as passage of monsoon disturbances associated with active phase and break monsoon periods whose periodicities vary from 3-5 and 10-15 days respectively. It is well noticed that summer monsoon rainfall in India varied from 604 to 1020 mm. The inter-seasonal variations in rainfall cause floods and droughts, which are the major climate risk factors in Indian Agriculture. The main unprecedented floods in India are mainly due to movement of cyclonic disturbances from Bay of Bengal and Arabian Sea on to the land masses during monsoon and post-monsoon seasons – and during break monsoon conditions in some parts of Uttar Pradesh and Bihar. The thunderstorms due to local weather conditions also damages agricultural crops in the form of flash floods. Beside floods, drought is a normal, repetitive feature of climate associated with deficiency of rainfall over extended period of time to different dryness levels describing its severity. During the period 1871 to 2009, there were 24 major drought years, defined as years with less than one standard deviation below the mean. Another important adverse effect of climate change could be unprecedented heat waves. Heat waves generally occur during summer season where the cropped land is mostly fallow, and therefore, their impact on agricultural crops is limited. However, these heat waves adversely affect orchards, livestock, poultry and rice nursery beds. The heat wave conditions during 2003 May in Andhra Pradesh and 2006 in Orissa are recent examples that have affected the economy to a greater extent. Also occurrence of heat waves in the northern parts during summer is common every year resulting in quite a good number of human deaths.Further, the water requirements of summer crops grown under irrigated conditions increase to a greater extent. Another adverse effect of climate change is cold waves which mostly occur in northern states. The Northern states of Punjab, Haryana, U.P., Bihar and Rajasthan experience cold wave and ground frost like conditions during winter months of December and January almost every year. The occurrence of these waves has significantly increased in the recent past due to reported climatic changes at local, regional and global scales. Site-specific short-term fluctuations in lower temperatures and the associated phenomena of chilling, frost, fogginess and impaired sunshine may sometimes play havoc in an otherwise fairly stable cropping/farming system of a region.

a) Influence of climate change on soil quality

Climate change is likely to have a variety of impacts on soil quality. Soils vary depending on the climate and show a strong geographical correlation with climate. The key components of climate in soil formation are moisture and temperature. Temperature and moisture amounts cause different patterns of weathering and leaching. Wind redistributes sand and other particles especially in arid regions. The amount, intensity, timing, and kind of precipitation influence soil formation. Seasonal and daily changes in temperature affect moisture effectiveness, biological activity, rates of chemical reactions, and kinds of vegetation. Soils and climate are intimately linked. Climate change scenarios indicate increased rainfall intensity in winter and hotter, drier summers. Changing climate with prolonged periods of dry weather followed by intense rainfall could be a severe threat to soil resource. Climate has a direct influence on soil formation and cool, wet conditions and acidic parent material have resulted in the accumulation of organic matter. A changing climate could also impact the workability of mineral soils and susceptibility to poaching, erosion, compaction and water holding capacity. In areas where winter rainfall becomes heavier, some soils may become more susceptible to erosion. Other changes include the washing away of organic matter and leaching of nutrients and in some areas, particularly those facing an increase in drought conditions, saltier soils, etc.

Not only does climate influence soil properties, but also regulates climate via the uptake and release of greenhouse gases such as carbon dioxide, methane and nitrous oxide. Soil can act as a source and sink for carbon, depending on land use and climatic conditions. Land use change can trigger organic matter decomposition, primarily via land drainage and cultivation. Restoration and recreation of peatlands can result in increased methane emissions initially as soils become anaerobic, whereas in the longer term they become a sink for carbon as organic mater accumulates. Climatic factors have an important role in peat formation and it is thus highly likely that a changing climate will have significant impacts on this resource.

b) Carbon build up and rising temperatures

In India, over two-thirds of the increase in atmospheric CO_2 during the past 20 years is due to fossil fuel burning. The rest is due to land-use change, especially deforestation, and to a lesser extent, cement production. Global average surface temperature increased 0.6 (0.2) ^oC in the 20th century and will increase by 1.4 to 5.8 ^oC by 2100. Estimates indicate that India's climate could become warmer under conditions of increased atmospheric carbon dioxide. The average temperature change is predicted to be in the range of 2.33^oC to 4.78^oC with a doubling in CO_2 concentrations. Over the past 100 years, mean surface temperatures have increased by 0.3-0.8^oC across the region. The 1990s have been the hottest decade for a thousand years. The time taken for CO2 to pass through the atmosphere varies widely, with a significant impact. It can take from 5 to 200 years to pass through the atmosphere, with an average of 100 years. This means that CO_2 emission produced 50 years ago still linger in atmosphere today. It also means that current emissions won't lose their deleterious effect until year 2104. Even though drastic measures to reduce climate emissions have been taken in recent years, climate change is impossible to prevent. As a result of increasing pressure from climate change on current key areas of food production, there might be a rising need for increased food production. The production of food more locally is also being promoted in an attempt to reduce food miles. To meet food production and security objectives, there might be the need to afford prime agricultural land more protection. The rise in temperatures will influence crop yields by shifting optimal crop growing seasons, changing patterns of precipitation and potential evapotranspiration, reducing winter storage of moisture in snow and glacier areas, shifting the habitat's of crops pests and diseases, affecting crop yields through the effects of carbon dioxide and temperature and reducing cropland through sea-level rise and vulnerability to flooding

c) Climatic change effect on soil fertility and erosion

No comprehensive study has yet been made of the impact of possible climatic changes on soils. Higher temperatures could increase the rate of microbial decomposition of organic matter, adversely affecting soil fertility in the long run. But increases in root biomass resulting from higher rates of photosynthesis could offset these effects. Higher temperatures could accelerate the cycling of nutrients in the soil, and more rapid root formation could promote more nitrogen fixation. But these benefits could be minor compared to the deleterious effects of changes in rainfall. For example, increased rainfall in regions that are already moist could lead to increased leaching of minerals, especially nitrates. In the Leningrad region of the USSR a one-third increase in rainfall (which is consistent with the GISS 2 x CO2 scenario) is estimated to lead to falls in soil productivity of more than 20 per cent. Large increases in fertilizer applications would be necessary to restore productivity levels. Decreases in rainfall, particularly during summer, could have a more dramatic effect, through the increased frequency of dry spells leading to increased proneness to wind erosion. Susceptibility to wind erosion depends in part on cohesiveness of the soil (which is affected by precipitation effectiveness) and wind velocity.

Nitrogen availability is important to soil fertility and N cycling is altered by human activity. Increasing atmospheric CO_2 concentrations, global warming and changes in precipitation patterns are likely to affect N processes and N pools in forest ecosystems. Temperature, precipitation, and inherent soil properties such as parent material may have caused differences in n pool size through interaction with biota. Keller et al., 2004 reported that climate change will directly affect carbon and nitrogen mineralization through changes in temperature and soil moisture, but it may also indirectly affect mineralization rates through changes in soil quality.

d) Impact on biodiversity

Climate change is having a major impact on biodiversity and in turn biodiversity loss (in the form of carbon sequestration trees and plants) is a major driver of climate change. Land degradation such as soil erosion, deteriorating soil quality and desertification are driven by climate variability such as changes in rainfall, drought and floods. Degraded land releases more carbon and greenhouse gases back into the atmosphere and slowly kills off forests and other biodiversity that can sequester carbon, creating a feed back loop that intensifies climate change.

4. Soil management techniques to mitigate ill effects of climate change:

In order to mitigate the ill effects of climate change on soil quality and to protect the soil and land resource, it is important to give more focus on conservation agriculture practices including conservation tillage, crop residue retention and recycling, effective crop rotations by way of including legumes in cropping systems, addition of animal based manures, adoption of soil water conservation practices, land cover management and mulching of soils with in-situ grown and externally brought plant and leafy materials etc. Some of these issues have been discussed in length in this lecture notes.

Conservation agriculture and its components

Conservation agriculture is a practice that reduces soil erosion, sustains soil fertility, improves water management and reduces production costs, making inputs and services affordable to small-scale farmers. Conservation agriculture is defined as a set of practices aimed at achieving the following three principles simultaneously: i) maintaining adequate soil cover, ii) disturbing the soil minimally, and iii) ensuring crop rotation and intercropping. Conservation agriculture as defined by Food and Agricultural Organizations (FAO) of the United Nations is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. It is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt the biological processes (Philip et al., 2007). Conservation agriculture, in broader sense includes all those practices of agriculture, which help in conserving the land and environment while achieving desirably sustainable yield levels. Tillage is one of the important pillars of conservation agriculture which disrupts inter dependent natural cycles of water, carbon and nitrogen. Conservation tillage is a generic term encompassing many different soil management practices. It is generally defined as 'any tillage system that reduces loss of soil or water relative to conventional tillage; mostly a form of non-inversion tillage allows protective amount of residue mulch on the surface (Mannering and Fenster, 1983).

Lal (1989) reported that the tillage system can be labeled as conservation tillage if it i) allows crop residues as surface mulch, ii) is effective in conserving soil and water, iii) maintains good soil structure and organic matter contents, iv) maintains desirably high and economic level of productivity, v) cut short the need for chemical amendments and pesticides, vi) preserves ecological stability and vii) minimizes the pollution of natural waters and environments. In order to ensure the above criteria in agriculture, there is a need to follow a range of cultural practices such as i) using crop residue as mulch, ii) adoption of non-inversions or no-tillage systems, iii) promotion of crop rotations by including cover crops, buffer strips, agroforestry, etc., iv) enhancement of infiltration capacity of soil through rotation with deep rooted perennials and modification of the root zone; v) enhancement in surface roughness of soil without jumping into fine tilth, vi) improvement in biological activity of soil fauna through soil surface management and vii) reducing cropping intensity to conserve soil and water resources and building up of soil fertility. The effects of conservation tillage on various soil properties, organic matter status, soil nutrient status and environmental quality have comprehensively reviewed by Blevins and Frye (1993), Lal (1989), Unger and McCalla (1980) and Unger (1990). From the various reviews, it is understood that no single tillage system is suitable for all soils and climatic conditions. The predominant advantages of the conservation tillage have been found in terms of soil erosion control, water conservation, less use of fossil fuels specifically for preparation of seed bed, reduced labour requirements, more timeliness of operations or greater flexibility in planting and harvesting operations that may facilitate double cropping, more intensive use of slopping lands and minimized risk of environmental pollution. Some of the discouraging and undesirable effects of conservation tillage has been reported as: (1) Increase in use of herbicides and consequently increased cost, (2) problems and difficulties in controlling of some of the infested weeds, (3) difficulty in managing poorly drained soils, (3) slower warming of temperate soils due to surface residue layer during winter and springs which delays germination and early growth. However, in tropics this negative aspect can become an asset in helping in maintaining relatively lower temperature and thereby enhancing germination. It also helps in preserving soil and water resources.

Importance and scope of conservation agricultural practices in rainfed areas

As discussed in the foregoing section, soil quality degradation is more prominent in rainfed agro-ecoregions because of natural and human induced crop husbandry practices, which call for the adherence to the conservation agriculture management as top priority. Conservation agriculture has the main aim of protecting the soil from erosion and maintaining, restoring and improving soil organic carbon status in the various production systems, hence more suited and required in rainfed agriculture. Predominantly, this goal can be achieved through minimizing the soil tillage, inclusion of crop rotation or cover crops (mostly legumes) and maintaining continuous residue cover on soil surface. The former is governed by the amount of draft, a farmer is using and the latter by the produce amount, harvesting index and fodder requirements including open grazing. The crop rotations are induced by crop diversification, which has wider scopes in the rainfed agriculture than in irrigated agriculture. Diversification will help not only in minimizing the risk occurred due to failure of crops, improving total farm income but also in carbon sequestration.

Tillage, which is one of the predominant pillars of conservation agriculture, disrupts the inter-dependent natural cycles of water carbon and nitrogen. Tillage unlocks the potential microbial activity by creating more reactive surface area for gas exchange on soil aggregates that are exposed to higher ambient oxygen concentration (21%). Tillage also breaks the aggregate to expose fresh surfaces for enhanced gas exchange and perhaps, may lead to more carbon loss from the interior that may have higher carbon-dioxide concentration. Thus, an intensive tillage creates negative conditions for carbon sequestration and microbial activity. However, the main question is whether the intensity of tillage or length of cultivation of land which is an environment enemy in production agriculture in terms of loss of carbon-dioxide, soil moisture through evaporation and biota dwindling is a major production constraint to agriculture or not. The developed countries suffer from heavy-duty mechanization, while India is suffering from long use of plough without caring much about the maintenance of land cover. The major toll of organic C in slopping lands has been taken by water erosion due to faulty methods of up and down cultivation.

Conservation agriculture vis-à-vis soil quality

Various research reports have emphasized that conservation agricultural practices play an important role in preventing the soils from further degradation and in restoring back the dynamic attributes of soil quality. According to Doran and Parkin (1994) and Karlen *et al.,* (1997), soil quality is defined as the functional capacity of the soil. 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.' 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 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. They provide signal about desirable or undesirable changes in land and vegetation management that have occurred or may occur in the future. Some of the important indicators which are given below can be influenced by appropriate soil management practices which in turn can help in moderating the ill effects of climate change (Table1).

Table 1: Major soil quality indicators and related processes and functions which can moderate the ill effects of climate change

Soil quality indicators	Soil processes and functions
i) Physical indicators	
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	
Effective rooting depth	Root growth, nutrient and water use efficiencies
Soil temperature	Heat flux, soil warming activity and species diversity of soil fauna
ii) Chemical indictors	
pH	Acidification and soil reaction, nutrient availability
Base saturation	Absorption and desorption, solubilization
Cation exchange capacity	Ion exchange, leaching
Total and plant available nutrients	Soil fertility, nutrient reserves
iii) Biological indicators	
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, biomass carbon, soil respiration and gaseous fluxes

Source: Lal (1994)

Role of conservation Agriculture (reduced tillage and residue management) in mitigating the adverse effect of climate change

Conservation tillage and residue management helps in the following ways in influencing some of the soil properties and mitigating the adverse effects of climate change.

- **Soil Temperature**: Surface residues significantly affect soil temperature by balancing radiant energy and insulation action. Radiant energy is balanced by reflection, heating of soil and air and evaporation of soil water. Reflection is more from bright residue.
- **Soil aggregation:** It refers to binding together of soil particles into secondary units. Water stable aggregates help in maintaining good infiltration rate, good structure, protection from wind and water erosion. Aggregates binding substances are mineral substances and organic

substances. Organic substances are derived from fungi, bacteria, actinomycetes, earthworms and other forms through their feeding and other actions. Plants themselves may directly affect aggregation through exudates from roots, leaves and stems, leachates from weathering and decaying plant materials, canopies and surface residues that protect aggregates against breakdown with raindrop impact, abrasion by wind borne soil and dispersion by flowing water and root action. Aggregates with. 0.84 mm in diameter is non-erodable by wind and water action. Well-aggregated soil has greater water entry at the surface, better aeration, and more water-holding capacity than poorly aggregated soil.

- Aggregation is closely associated with biological activity and the level of organic matter in the soil. The gluey substances that bind components into aggregates are created largely by the various living organisms present in healthy soil. Therefore, aggregation is increased by practices that favor soil biota. Because the binding substances are themselves susceptible to microbial degradation, organic matter needs to be replenished to maintain aggregation. To conserve aggregates once they are formed, minimize the factors that degrade and destroy them.
- Well-aggregated soil also resists surface crusting. The impact of raindrops causes crusting on poorly aggregated soil by disbursing clay particles on the soil surface, clogging the pores immediately beneath, sealing them as the soil dries. Subsequent rainfall is much more likely to run off than to flow into the soil. In contrast, a well-aggregated soil resists crusting because the water-stable aggregates are less likely to break apart when a raindrop hits them. Any management practice that protects the soil from raindrop impact will decrease crusting and increase water flow into the soil. Mulches and cover crops serve this purpose well, as do no-till practices which allow the accumulation of surface residue.
- **Soil density and porosity:** Soil bulk density and porosity are inversely related. Tillage layer density is lower in ploughed than unploughed (area in grass, low tillage area etc). When residues are involved, tilled soils will reflect lower density. Mechanization with heavy machinery results in soil compaction, which is undesirable and is associated with increased bulk density and decreased porosity. Natural compaction occurs in soils, which are low in organic matter and requires loosening. But, practicing conservation tillage to offset the compaction will be effective only when there is adequate residue, while intensive tillage may adversely influence the soil fauna, which indirectly influence the soil bulk density and porosity.
- **Effects on other physical properties:** Tillage also influences crusting, hydraulic conductivity and water storage capacity. It has been understood that the textural influences and changes in proportion of sand, silt and clay occur due to inversion and mixing caused by different tillage instruments, tillage depth, mode of operation and effect of soil erosion. Soil crusting which severely affects germination and emergence of seedling is caused due to aggregate dispersion and soil particles resorting and rearrangement during rainstorm followed by drying. Conservation tillage and surface residue help in protecting the dispersion of soil aggregates and helps in increasing saturated hydraulic conductivity. Increased HC in conjunction with increased infiltration resulting from conservation tillage allows soil profile to be more readily filled with water. Further, less evaporation is also supported by conservation tillage, and profile can retain more water.
- **Effect on soil organic matter and soil fertility:** Conservation agricultural practices help in improving soil organic matter by way of i) regular addition of organic wastes and residues, use of green manures, legumes in the rotation, reduced tillage, use of fertilizers, and supplemental irrigation ii) drilling the seed without disturbance to soil and adding fertilizer through drill following chemical weed control and iii) maintaining surface residue, practicing reduced tillage, recycling of residues, inclusion of legumes in crop rotation. These practices provide great opportunity in maintaining and restoring soil quality in terms

of SOM and N in SAT regions. It is absolutely necessary to spare some residue for soil application, which will help in improving soil tilth, fertility and productivity.

Some research experiences showing the effect of conservation management practices on soil quality improvement

There are several reports on the influence of conservation agricultural management practices comprising of tillage, residue recycling, application of organic manures, green manuring and integrated use of organic and inorganic sources of nutrients, soil water conservation treatments, integrated pest management, organic farming, etc., on soil quality. Improved soil quality parameters create additional muscle power to soil to combat the ill effects of climate change. Some of the results pertaining to the effect of conservation agricultural practices on soil quality are given below:

The studies conducted over a 9 year period in Alfisols at Bangalore with finger millet, revealed that the yields were similar with optimum N, P, K application and with 50% NPK applied through combined use of fertilizers + FYM applied @ 10 t ha^{-1}. Application of vermicompost in combination with inorganic fertilizer in 1:1 ratio in terms of N equivalence was found very effective in case of sunflower grown in Alfisol at Hyderabad (Neelaveni, 1998). Combined use of crop residues and inorganic fertilizer showed better performance than sole application of residue. Use of crop residue in soil poor in nitrogen (Bangalore) showed significant improvement in the fertility status and soil physical properties. Continuous addition of crop residues for five years enhanced maize grain yield by 25%. Organic matter status improved from 0.5% in the control plots to 0.9% in plots treated with maize residue at 4 t ha^{-1} $year^{-1}$. In Alfisols at Hyderabad, use of crop residues in pearl millet and cowpea not only enhanced the yields but also made appreciable improvements in stability of soil structure, soil aggregates and hydraulic conductivity.

Capitalisation of legume effect is one of the important strategies of tapping additional nitrogen through biological N fixation. There are many reports on this aspect (Singh and Das, 1984; Sharma and Das, 1992). The beneficial effect of preceding crops on the succeeding non-legume crops has been studied at many locations. When maize was grown after groundnut, a residual effect of equivalent to 15 kg N ha^{-1} was observed at ICRISAT (Reddy et al. 1982). Sole cowpea has been reported to exhibit a residual effect of the magnitude of 25-50 kg N ha^{-1} (Reddy et al. 1982). Based on a five year rotation of castor with sorghum + pigeon pea and green gram + pigeon pea in an Alfisol of Hyderabad, it was observed that green gram + pigeon pea intercrop (4:1) can leave a net positive balance of 97 kg ha^{-1} total N in soil (Das et al. 1990).

Results of a long-term study conducted on soil quality improvement revealed that the application of gliricidia loppings proved superior to sorghum stover and no residue treatments in maintaining higher soil quality index (SQI) values. Further, increasing N levels also helped in maintaining higher SQI. Among the 24 treatments, the highest SQI was obtained in conventional tillage (CT) + gliricidia loppings (GL) + 90 kg N ha^{-1} ($CTGLN_{90}$) (1.27) followed by $CTGLN_{60}$ (1.19) and minimum tillage (MT) + sorghum stover (SS) + 90 kg N ha^{-1} ($MTSSN_{90}$) (1.18), while the lowest was under minimum tillage + no residue (NR) + 30 kg N ha^{-1} ($MTNRN_{30}$) (0.90) followed by $MTNRN_{0}$ (0.94), indicating relatively less aggradative effects. The application of 90 kg N ha^{-1} under minimum tillage even without applying any residue ($MTNRN_{90}$) proved quite effective in maintaining soil quality index as high as 1.10. The key indicators, which contributed considerably towards SQI were, available N, K, S, microbial biomass carbon (MBC) and hydraulic conductivity (HC). Among the various treatments, $CTGLN_{90}$ not only had the highest SQI, but was most promising from the viewpoint of sustainability, maintaining higher average yield levels under sorghum-castor rotation. From the view point of SYI, CT approach remained superior to MT. To maintain yield as well as soil quality in Alfisols, primary tillage along with organic residue and nitrogen application are needed (Sharma et al, 2005).

Another long-term experiment was conducted with two tillage (conventional (CT) and reduced (RT)) and five INM treatments (control, 40 kg N through urea, 4 t compost + 20 kg N, 2 t Gliricidia loppings + 20 kg N and 4 t compost + 2 t Gliricidia loppings) using sorghum and green gram as test crops. Tillage did not influence the soil quality index (SQI), while the conjunctive nutrient use treatments had a significant effect. 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. Statistically, the overall superiority of the treatments in aggrading the soil quality was: 4 Mg compost + 2 Mg gliricidia loppings (T5) > 2 Mg Gliricidia loppings + 20 kg N through urea (T4) = 4 Mg compost + 20 kg N through urea (T3) > 40 kg N through urea (T2). The extent of percent contribution of the key indicators towards soil quality index (SQI) was: microbial biomass carbon (MBC) (28.5%), available nitrogen (28.6%), DTPA-Zn (25.3%), DTPA- Cu (8.6%), hydraulic conductivity (HC) (6.1%) and mean weight diameter (MWD) (2.9%) (Sharma et al., 2008).

Based on the network tillage experiment being carried out since 1999 at various centers of All India Coordinated Research Project on Dryland Agriculture (AICRPDA), it was observed that in arid (< 500 mm rainfall) region, low tillage was almost comparable to conventional tillage and the weed management was not so difficult, whereas, in semi arid (500 – 1000 mm) region, conventional tillage was found superior. It is a well-established fact that infiltration of rainfall depends on soil loosening and its receptiveness and thus requires more surface disturbance. Success of crops depends on rainfall infiltration and soil moisture holding in the profile.
For improving the carbon content in soil, apart from crop residues, the agro-forestry also becomes important. However, nothing comes free. The agro-forestry system comprising of perennial components depends on the sub-soil components. It has been observed that grasslands and tree system play an important role in improving soil properties such as bulk density, mean weight diameter, water stable aggregates and organic carbon. Apart from the above, other soil properties such as infiltration rate and hydraulic conductivity were also influenced due to agro forestry systems compared to agricultural systems.

How to promote conservation agriculture for improving soil quality:

The following steps are needed to promote conservation farming in the future:

1) There is a need to create awareness among the communities about the importance of soil resources, organic matter build up in soil. Traditional practices such as burning of residues, clean cultivation, intensive tillage and pulverization of soil upto finest tilth need to be discouraged.

2) Systems approach is essential for fitting conservation tillage in modern agriculture. In order to follow the principle of “grain is to man and a residue is to soil”, farming systems approach introducing alternative fodder crops is essential. Agroforestry systems with special emphasis on silvipastures systems need to be introduced. Unproductive livestock herds needs to be discouraged

3) For the adoption of conservation tillage, it is essential that complete package of practices may be identified based on intensive research for each agro ecological region.

4) The increased use of herbicides has become inevitable for adopting conservation tillage/conservation farming practices. The countries that use relatively higher amount of herbicides are already facing problem of non-point source pollution and environmental hazard. In order to reduce the herbicidal demand, there are scopes to study the allelopathic effects of cover crops and intercultural and biological method of weed control. In other words, due concentration is needed to do research on regenerative cropping systems to reduce dependence on inorganic chemicals.

5) Low tillage, crop rotation, cover crops, maintenance of residues on the surface, control of weeds through herbicides, are the key components of conservation farming. Therefore, it is essential that these themes must be studied in depth under diverse soil and climatic conditions across the country on long-term basis.

6) The other objective of conservation farming is to minimize the inputs originating from non-renewable energy sources. Eg. Fertilizers and pesticides. Hence, research focus is required on enhancing fertilizer use efficiency and reduction in use of pesticides. This aspect can be strengthened by following integrated nutrient management and integrated pest management approach.

7) The past research experiences of conservation tillage reveal that the major toll of yield is taken by poor germination and poor crop stand because of poor microclimatic environment and hard setting tendencies of soil, excessive weed growth and less infiltration of water to the crop root zone. Therefore, the important aspects which need concentrated research focus include appropriate time of sowing, suitable seed rate, depth of seed placement and soil contact, row orientation, etc. Suitable cultivars having responsiveness to inputs also become important component of conservation farming.

8) The issues related to development of eco-friendly practices for tillage and residue recycling – appropriately for specific combination of soil-agro climatic cropping system – to alleviate physical constraints with higher water and nutrient use efficiency need to be addressed.

9) Inter-disciplinary research efforts are required to develop appropriate implements for seeding in zero tillage, residue incorporation and inter-cultural operations.

Research focus is needed on modeling of tillage dynamics and root growth, incorporation of soil-physical properties in crop-growth simulation models and relating it to crop yields under major cropping sequences.

Research and management strategies to improve soil resilience towards climatic change

The following research, developmental and policy strategies are suggested to restore and maintain soil quality on long-term basis.

- **Checking soil resource through effective soil and water conservation (SWC) measures**: It is well accepted connotation that 'Prevention is better than cure'. In order to protect the top soil, organic mater content contained in it and associated essential nutrients, it is of prime importance that there should be no migration of soil and water out of a given field. If this is controlled, the biggest robbery of clay-organic matter -nutrients is checked. This can be easily achieved, if the existing technology on soil and water conservation is appropriately applied on an extensive scale. The cost for in-situ and ex-situ practices of SWC has been the biggest concern in the past. There is a need to launch 'soil resource awareness program' among the farming community. Suitable incentives / support need to be given to the farming community by way of employment / food for work program, etc.

- **Rejuvenation and reorientation of soil testing program in the country:** About more than 600 Soil testing labs situated in the country need to be reoriented, restructured and need to be given fresh mandate of assessing the soil quality in its totality including chemical, physical, biological soil quality indicators and water quality. The testing needs to be on intensive scale and recommendations are required to be made on individual farm history basis. Special focus is required on site specific nutrient management (SSNM). Soil Health Card system needs to be introduced. Soil fertility maps of intensive scale need to be prepared. District soil testing labs need to be renamed as 'District Soil Care Labs' and required to be well equipped with good equipments and qualified manpower for assessing important soil quality indicators including micronutrients. Fertilizer application needs to be based on soil tests and nutrient removal pattern of the cropping system in a site specific manner. This will help in correcting the deficiency of limiting nutrients. Keeping in mind the sluggish and inefficient activities of regional soil testing labs of the states, private sector can also be encouraged to take up Soil Care Programs with a reasonable costs using a principle of 'Soil Clinics, Diagnosis and Recommendation'.

- **Promotion of management practices which enhance soil organic matter**: Management practices such as application of organic manures (composts, FYM, vermi-composts), legume-crop based green manuring, tree-leaf green manuring, residue recycling, sheep-goat penning, organic farming, conservation tillage, inclusion of legumes in crop rotation need to be encouraged (Sharma et al., 2002, 2004). Similar to inorganic fertilizer, subsidy provisions for organic manures can also be made so that growers should be motivated to take up these practices as components of integrated nutrient management (INM). As is being done in some of the countries such as USA, conservation tillage and land cover need to be promoted in India too for better carbon sequestration.

- **Development and promotion of other bio-resources for enhancing microbial diversity and ensuring their availability**: In addition to organic manures, there is a huge potential to develop and promote bio-fertilizers and bio-pesticides in large scale. These can play an important role in enhancement of soil fertility and soil biological health. Use of toxic plant protection chemical can also be reduced. In addition to this, there is a need to focus on advance research for enhancing microbial diversity by identifying suitable gene pools.

- **Ensuring availability of balanced multi-nutrient fertilizers:** Fertilizer companies need to produce multi-nutrient fertilizers containing nutrients in a balanced proportion so that illiterate farmers can use these fertilizers without much hassle.

- **Enhancing the input use efficiency through precision farming:** The present level of use efficiency of fertilizer nutrients, chemicals, water and other inputs is not very satisfactory. Hence, costly inputs go waste to a greater extent and result in monetary loss and environmental (soil and water) pollution. More focus is required to improve input use efficiency. The components required to be focused could be suitable machinery and other precision tools for placement of fertilizers, seeds and other chemical in appropriate soil moisture zone so that losses could be minimized and efficiency could be increased. This aspect has a great scope in rainfed agriculture. This will also help in increasing water use efficiency (WUE) too.

- **Amelioration of problematic soils using suitable amendments and improving their quality to a desired level:** History has a record that poor soil quality or degraded soils have taken toll of even great civilizations. No country can afford to let its soils be remaining degraded by virtue of water logging, salinisation, alkalinity, erosion etc. Lots of efforts have already gone into the research process. There is a need to ameliorate the soils at extensive scale on regular basis. No matter, how much it costs.

- **Land cover management:** Promotion of land cover management is must to protect the soil and to enhance organic matter in soil.

- **Mass awareness about the importance of soil resource and its maintenance:** There is need to introduce the importance of soil resource and its care in the text books at school and college levels. The subject is dealt at present apparently along with geography. Farming communities too need to be made aware about soil, its erosion, degradation, benefits and losses occurred due to poor soil quality. This can be done through various action learning tools which explain the processes of soil degradation in a simple and understandable manner.

- **Need to constitute a high power body such as National Authority on Land and Soil Resource Health or National Commission on Soil Resource Health:** State Soil and Water conservation departments restrict their activities only up to construction of small check dams, plugging of gullies etc in common lands. State Soil testing labs are almost sluggish in action, poorly equipped and are with under-qualified manpower. Mostly, no tests are done except for Organic C, P and K. State agricultural universities (SAU) only adopt few villages, and consequently, no extensive testing of soil health is done. ICAR institutions also take up few watersheds. Then, there will be no one to work for Soil Health Care program at extensive scale. Hence, a Central High Power Authority / Commission on soil Resource Health is needed to coordinate the program with States. It is beyond the capacity of research organizations to take up such giant and extensive task in addition to their regular research mandates.

Conclusion

Soil is Gods gift to Nation. Mans' success in responding to the latest challenge that of global climate change will depend on how we manage this vital resource
Healthy Soils - Better Environment - Better Nutrition – Healthy Society – Healthy Natio

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Role of Soil Physical Properties in Soil Health Management in Rainfed Areas

A. K. Indoria
ICAR-Central Research Institute for Dryland Agriculture, Hyderabad-500 059
Author email: akumar.indoria@crida.in

Introduction:

Rainfed soils of India are generally poor in soil quality viz., low in fertility status, low in organic matter status, weak in buffering and resilient capacity, high in erodibility, fragile in nature, shallow in depth and susceptible to loss of physical integrity. In rainfed arid and semi-arid areas, these soils suffer from excess of salts (saline-alkali soils) and in sub-humid rainfed areas suffer from acidity (acid soils). In *rainfed* regions, among several crop and climate related constraints, poor soil physical health is one of the major constraints which severely limit crop productivity. The knowledge of the physical properties of soil is essential in defining and/or improving soil health to achieve optimal productivity for each soil/climatic condition. Different management technologies viz., integrated nutrient management, tillage practices, mulching, addition of clay, surface compaction, conservation tillage, use of polymers etc can favourably modify the soil physical properties like bulk density, porosity, aeration, soil moisture, soil aggregation, water retention and transmission properties and soil processes like evaporation, infiltration, runoff and soil loss, ultimately help in better crop growth and yield in rainfed areas.

Major soil physical constraints for crop production:

The predominant soil physical constraints for successful crop production in these areas are: (i) poor soil structure and texture, (ii) high or low permeability, (iii) surface seal and crusting, (iv) low or high infiltration capacity, (v) poor water retentive capacity, (vii) wind and water erosion, (viii) poor organic matter status. Nearly two-thirds of India's land mass has more than 3% slopes and is highly undulating topography. Major soil physical constraints in rainfed areas and their effect on soil and plant health are shown in the Table 1.

Table 1: Major soil physical constraints in rainfed areas and their effect on soil and plant health.

Soil Physical constraints	Effect on soil and plant health
Coarse texture	Poor water and nutrient retentive capacity
Shallow depth	Restricted to root growth
Water erosion	Loss of top fertile soil, resulting in deficiencies of several nutrients and organic matter
Low organic matter	Sparse vegetation with little residues
Poor stucture	Poor water and nutrient retentive capacity
Wind erosion	Movement of top fertile soil
Undulating topography	Tillage operation and seeding germination problems
Sub surface hardpan	Uneven soil wetting and root growth restriction
Imbalance permeability	Wetness for too long period (slow permeable soil) or speedy drainage (high rainfall soil)
Surface crusting	Poor seedling emergence
Water logging	Ill effect on soil plant health

Soil physical constraints-Area and distribution of important rainfed soil orders:

Out of an estimated 142 million ha net cultivated area, about 83 million ha is *rainfed* and it is estimated that even after reaching the full irrigation potential, nearly 50% of the cultivated area will remain *rainfed*[1]. According to an estimate, about 90 million hectare of the area in the country suffers from the different soil physical constraints (Table 2). At present, nearly 70% of *rainfed* area is affected by wind erosion and sand deposition. Shallow depths and soil hardening are the major soil physical constraint in *rainfed* regions, followed by high permeable soil, sub surface hard pan, surface crusting and temporarily water logging.

Table 2: Distribution of area (million ha) affected by various soil physical constraints in India[2].

Physical constraints	Area	Main states affected
Shallow depths	26.40	Andra Pradesh, Maharastra,, West Bengal, Kerala and Gujarat
Soil hardening	21.57	Andra Pradesh, Maharastra and Bihar
High permeability	13.75	Rajasthan, West Bengal, Gujarat, Punjab and Tamil Nadu
Sub surface hard pan	11.31	Maharastra, Punjab, Bihar, Rajasthan, West Bengal and Tamil Nadu
Surface crusting	10.25	Haryana, Punjab, West Bengal, Orrisa and Gujarat
Temporarily water logging	6.24	Madya Pradsh, Maharastra, Punjab, Gujrat, Kerala and Orrisa

Major soil orders which represent *rainfed/dryland* regions in India are Alfisols, Vertisols, Entisols and other associated soils. Other soil orders such as Oxisols, Inceptisols and Aridisols also form a considerable part of *rainfed/dryland* agriculture system. In dryland regions, nearly 30% of soils are covered by Alfisols, nearly, 35% of soils are covered by Vertisols and associated soils (having vertic properties), nearly 10% of soils are covered by Entisols and nearly 4% of soils are covered by Aridisols. The areas (more than 85% of the total areas of respective soil order) of rainfed soil orders which present in different states of India are given in Table 3.

Table 3. Area under major soil orders in *rainfed/dryland* regions in different states[3].

Soil Order	Main states posses area more than 85% of the total areas of the respective soil order
Alfisol	Andra Pradesh, Madhaya Pradesh, Bihar, Karanataka, Odisha, Tamil nadu, West Bangal, Utter Pradesh, Assam and Maharastra.
Vertisol	Madhaya Pradesh, Maharastra, Karanataka, Andra Pradesh, Gujrat, Rajasthan, Tamil Nadu, Odisha and Utter Pradesh.
Entisol	Rajasthan, Jammu & Kashmir, Maharastra, Madya Pradesh, Utter Pradesh, Bihar, Arunchal Pradesh, Karanataka, Andhra Pradesh, Assam, Himachal Pradesh, Gujrat, West Bangal, Odisha, Harayana, Punjab, Tamil Nadu, Mizoram and Manipur.
Aridisol	Rajasthan, Gujarat, Karanataka, Andra Pradesh Punjab and Haryana.

Causes of poor soil physical health in *Rainfed* areas:

The inherent properties of rainfed soil and climatic conditions prevailed in these areas accelerate the poor soil physical health. Although, lack of suitable preventive measures to control the poor soil physical health and faulty management practices trigger the poor soil physical health again in negative direction.The various predominant causes of soil poor soil physical health include: (i) water and wind erosion ((ii) intensive deep tillage (iii) repetitive cultivation (iv) mono cropping (v) nutrient imbalance, (vi) low use of the organic manure, (vii) removal of vegetation, ((viii) uncontrolled and excessive grazing, and (ix) unprotected fields are known to cause soil physical deterioration in *rainfed* areas[4].

Important soil physical constraints in *rainfed* areas:

Crusting and hardening

Surface crusting and hardening is the most frequently reported physical problem in *rainfed* areas because these soils predominantly are light textured soils particularly in surface horizons due to less clay percentage except Vertisols. The soils in *rainfed* region in Andra Pradesh, Haryana, Rajasthan, Uttar Pradesh, Bihar and West Bengal form a crust on the soil surface which interferes with germination and growth of the crops. The red sandy loam soil (Alfisols) is soft when wet but becomes very hard on drying due to presence of sesquioxides. In these soils, the packing of clay particles to form a more extensive interleaving domain produces a massive and hard structure with a minimum porosity. The crust formed on the surface in the *rainfed* soil offers mechanical impedance during the early stages of crop growth to the emerging plumes of the seedlings which bends below it and tries to come out at weak points, some seedlings are injured at their tips and failed to emerge.

Soil textural and structural

Alfisols of the *rainfed* areas are generally characterized by light-texture (due to leaching of the clay in below horizons) and shallow depths. In rainfed Alfisol soils, clay content (ie, most reactive part of the soil in terms of the actual seat of reactions) in profile ranges between 30-40% but in surface horizons it varies 20 -25%[3]. Due to less clay content and organic matter in surface horizons, lack of aggregation or presence of unstable aggregation is the tendency of the soils to reduce surface roughness, rapidly seal the surface after rainfall and produce crusting with subsequent drying cycles. The fine clay percentage is more in Vertisol soils as compared to the other soils present in *rainfed* areas. The clay content of Vertisols remains uniformly high (>35%) throughout the profile to a depth of at least 50 cm or more[3]. The clay content of the *rainfed* Entisol and Aridisols also low in surface horizons and widely varies at different location in different crop production systems[5]. In rainfed areas, soil structure problems in different regions are associated with texture, topography and rainfall. The predominant soil structural associated problems include crusting and hardening with sandy loam texture of alluvial (Inceptoisols and Entisols), red (Alfisols) and laterites (Ultisols and Oxisols), slow permeability with clay and silty clay loam textutre of black soils (Vertisols) and high permeability with sand and loamy sand texture of desert soils (Aridisols).

Sub surface hard pan and compactness

This problem is more severe in areas where dryness is most pronounced and in soils that contain large amount of very fine sand and coarse silt (Alfisol, Aridisols, Entisols). The subsoil hard pan in red soil is due to the illuviation of clay to the sub soil horizons coupled with cementing action of oxide of iron, aluminium and calcium carbonate, which increase the soil bulk density to more than 1.8 Mg m^{-3}. Further, the hard pan can also develop due to continuous cultivation of crops using heavy implements up to certain depths constantly. Alfisols also contain distinct layers of gravel and weathered rock fragments at lower depths, often called 'murram'. The rooting depth of crops is limited by presence of such layers or by compact argillic horizon. The increase in bulk density decreases the hydraulic conductivity and water diffusivity in black silt clay loam and infiltration rate in *rainfed* alluvial loam soils (Entisols, Aridisols and Inceptisols). The higher bulk density in these areas include low reduction in the infiltration rate due to less porosity and compacted soil which restricts the entry of water in to the soil , hence more water remains on the soil surface.

High permeability

The high permeability and poor nutrient retention capacity is associates with sand and loamy sand texture of *rainfed* soils (Entisols, Aridisols and Inceptisols). Due to high permeability, most of the rain water is lost in deeper soil layer and the availability of water in upper soil profile is for very short period. The high permeability and poor nutrient retention capacity of soils reduce the water and fertilizer use efficiency and cause water logging in areas having impervious layer at shallow depths. The low fertilizer use efficiency and high nutrient losses do not encourage the farmer to use high levels of inputs, resulting in low yields of pearl millet, maize, wheat and barley in western India and sorghum, maize, finger millet and sugarcane in sourthern India.

Slow permeability and extremes of consistence

Slow permeability is associated with black Vertisol soils of *rainfed* regions. Due to slow permeability, at the time of the heavy rainfall, water stagnate in the field, paddy crop fails in low-land areas and most of the upland crops like sorghum and maize produce low yields. The prevailing anaerobic condition causes the accumulation of carbon dioxide and other toxic by-products in this zone which restrict the root growth. In the *rainfed* areas, where natural slope is less than 1.5%, crop growth suffers due to temporary water logging of soil which develops oxygen stress in the root zone. In some areas, water may accumulate on the soil surface from few centimetres to more than 50 cm. Vertisols offer extremes of consistence. They are very hard when dry and very sticky and plastic when wet. Extreme hardness when dry and stickiness and loss of trafficability when wet, permit tillage and seedbed preparation only within a very narrow range of moisture contents.

Soil water retention characteristics and poor plant available water content

Clay content showed highly significant positive correlation with water retention parameters in all the soil types of *rainfed* soils. Study conducted by Rao *et al.*[5] in different soils of *rainfed* regions revealed that water retention at 0.33 bar and 15 bar of various soil types was positively correlated to clay content. In Vertisols and associated soils with high clay content, higher water retention at both the tensions was observed. Study conducted by Kadu *et al.*[6] revealed that in Vertisol soils with high exchangeable Na^+, the water was held at higher tension and thus unavailable to plants.

Thus in case of the Alfisols, Aridisols and Entisols, the water retention is poor due to the low clay content, while in case of Vertisols, the high Na^+ ion disturbed the water retention phenomenon.

Water transmission characteristics

A good distribution of pores throughout a soil profile is vitally important for crop growth which is important for water, air and nutrient to circulate in the soil. The *rainfed* regions soil particularly Entisols and Aridisols contain good hydraulic conductivity. But in case of Alfisols, lack of contents of fine clay particles and low amount of organic matter within the soil matrix limit the water transmission characteristics. Alfisols in these areas are mostly structureless or massive and hence have low hydraulic conductivity. ESP is an important factor which positively contributes to water retention but negatively to water movement (saturated hydraulic conductivity) and yield of crop in Vertisol. The subsoil sodicity impaired the hydraulic properties as evident from the significant negative correlation value between ESP and saturated hydraulic conductivity in Vertisols[7]. They also reported that significant negative correlation between extractable Mg and saturated hydraulic conductivity (r=0.705) indicates the deterioration of hydraulic properties due to clay dispersion caused by Mg^{+2} ions.

Infiltration characteristics

If soil is having high infiltration rate (as in case of Entisol and Ariddsols), water applied through irrigation and received through rainfall enters in to the soil as early as possible which in turn reduces the evaporation and run off losses. Low water holding capacity of the SAT Alfisols can be attributed to the fact that little water is transmitted to deeper layers of the profile due to poor porosity as a result of seal formation. Organic carbon (OC) content of Vertisols is low to moderate due to higher rate of decomposition in semi-arid environment. Besides the higher exchangeable sodium content of clay complexes in black soils, these soils also suffer from compactness of the subsoil layer. All, put together, these soils have low infiltration and percolation rates, less nutrient movements and free air transport within the soil profile. This invariably leads to decrease in water movement through soil profile and deep percolation[32].

Management technologies for *rainfed* soils

In this section, we have tried to summarise the impact of management technologies for alleviating the soil physical constraints for the enhancement of crop yield in rainfed regions of India. No doubt, if these soils are managed properly for good physical health, the yield potentials of different crops can be increased significantly. Although the soil physical management technologies are location specific and the benefits from their adoption are highly variable depending on the rainfall intensity, slope and texture of the soil besides the prevailing crop/cropping system.

Management technologies for soil crust formation constraint

To overcome the problem of crusting several researchers reported that mechanical breaking of crust by hoeing and continuous incorporation of stubble or crop residues to the land helped in minimising crust formation in these soils. Study conducted by Phogat and Dahiya[8] revealed that application of FYM on seed lines as mulch increased the seedling emergence over the crusted soil by three and tenfold in pearl millet and cotton, respectively. Addition of slow decomposing residues like paddy husk, coir pith etc fallowed by appropriate tillage has proved very useful in red *chalka* soils of rainfed areas. The efficiency of various amendments at different rates was evaluated for major crops of the area and their efficiency was found in the order: FYM @ 10 t> coir pith @20 t > powdered groundnut shell @ 5 t > gypsum @ 4 t > paddy husk @ 5 t ha^{-1}. They further reported that application on seed line as mulch of organics such as wheat busha, rice husk and FYM @ 2-3 t ha^{-1} was most effective in reducing the crust strength and increasing the yield of crop[2].

Researchers also emphasized on the timely sowing, appropriate method of sowing and proper use of the implements in *rainfed* region to over come the soil crusting constraint and subsequently increase the seed germination and productivity in *rainfed* crops[9]. Sowing of the *rainfed* crops on shoulders of ridges under ridge-furrow system of cultivation helps in lowering the crust problem encountered in seeding emergence. By this system of cultivation, the crust is formed in the furrow as the soil particles responsible for soil crusting are transported from ridge side to furrow bottom with rain water. Also due to inter row water harvesting of the rain, the furrow remain wet for longer time thus preventing to develop crust strength critical to seeding emergence. Soil moisture contents close to field capacity are most favorable for seed emergence in crusty soils. Timely sowing of the *rainfed* crops could be one of the strategies for higher crop productivity. It was observed that in *rainfed* Alfisols at Hyderabad, the germination percentage in Precision planter sown plot was 10.5% higher than the conventional planter in different crops[10].

Management technology for highly permeable *rainfed* soils

Compaction

In light texture soils, about 25-40% of rainfall can percolate down below the root zone of crops. Consequently, a small quantity of rainfall could be considered *insitu*. Under such conditions, the *rainfed* crops are unable to sustain even short (>10 days) dry spell. Soil compaction by giving a few passes of heavy duty roller was attempted by several researchers[11,12]. Compaction by 12 passes of half ton roller could increase bulk density of top 30 cm soil layer from 1.55 to 1.67 Mg m^{-3} and increased the yield of pearl millet at Jobner (Rajasthan) by 33% over the control yield. Similar results were obtained by Indoria *et al.* [11] in *rainfed* cow pea crop and noticed 23% more seed yield and 9% more stover yield recorded with the passing of 500 kg iron roller two times over uncompacted soil. In other crops like barley, cluster bean, cotton, mustard, pearl millet and wheat the yield increase was in the tune of 34, 25, 7, 13, 31, and 32%' respectively over uncompacted[3]. Indoria *et al.* [11]reported that compacted soil retained 15 to 33% more moisture in different soil layers and decreased the saturated hydraulic conductivity under *rainfed* condition (Table 4).

Table 4. Effect of compaction on soil moisture content (%) and saturated hydraulic conductivity (cm h^{-1}) in soil layers at different stages of crop growth in cowpea[11].

Soil depth (cm)	Moisture content (%) and saturated hydraulic conductivity (cm h^{-1}) (saturated hydraulic conductivity values presented in brackets)					
	Just after compaction		At flowering		At harvest	
	C_O*	C_2*	C_O	C_2	C_O	C_2
0-15	9.4 (10.4)	11.6 (8.9)	10.0 (10.6)	12.63 (9.1)	7.2(10.7)	9.1 (9.3)
15-30	9.9 (9.6)	12.1 (7.2)	10.6 (9.7)	12.94 (7.4)	7.7(9.9)	9.9 (7.5)
30-45	10.5 (8.7)	12.0 (7.4)	11.0 (8.8)	12.68 (7.6)	7.8 (8.9)	9.5 (7.7)

C_O*=No compaction and C_2*=two passing of 500 kg iron roller

Compaction plus clay addition

In arid regions of the Rajasthan, **c**ompaction was imparted after addition of the 2% clay. In this case the results in terms of water and nutrient retention and yield sustainability have been phenomenal in desert soil, hence, referred as to Desert Technology. A low cost roller (named, JRIC roller) was designed and fabricated at Jobner (Rajasthan) for implementing this technology. Yadav and Majumdar[12] indicated that 4 passes of 500 kg iron roller after mixing of 2% clay increased the moisture retention capacity and reduced saturated hydraulic conductivity and infiltration rate of loamy sand soil over control. This technology successfully demonstrated at adaptive farmer's field for wheat and pearl millet crop and 29 and 37 % yield, respectively increase was observed[2].

Management technologies for sub-surface mechanical impedance and compactness

Formation of a hard pan below the ploughing depths restricts infiltration of the rain water into the sub-soil besides restricting root proliferation. Mechanical shattering of these hard pans by chiselling or mould board ploughing help in improving infiltration and water storage capacity of the solum besides a good improvement in the yield of different crop in *rainfed* regions[13]. Application of chisel technology (up to 45 cm at 50 cm interval) in red soil at Coimbatore, there was 18.6 to 64.1 % yield increase over farmers practices in different *rainfed* crops viz, sorghum, maize, ground nut, tomato, black gram etc. Similarly, in black soil at Nizamabad (Andra Pradesh), 12% yield increase was noticed with the chisel technology (30 cm soil depth at 60 cm interval), and at same location chisel plus amendment (gypsum @ 5 t ha^{-1} or FYM @ 25 t ha^{-1}, 25.4% yield increase was noticed in sugarcane at farmers field[2]. In sandy loam soil at Hisar (Haryana), there was 14, 17, and 41% yield increased in wheat, cotton and raya, respectively due to chieselling (up to 40 cm depth at 50 cm interval)[13]. Ameliorative tillage practices particularly deep tillage (sub soiling with chisel plough) can improve the water storage of soil by facilitating infiltration, which may help in minimizing water stress in this type of soil. The faster infiltration rate and water storage of the profile facilitated higher grain yield and enhanced water use efficiency for soybean under sub soiling than conventional tillage[14].

Management technologies for water retention

Soil organic matter is an integral to managing water cycles in ecosystems and its depletion have significant negative impacts on soil physical properties (infiltration, aggregate stability, porosity, water content, bulk density) and plant productivity. Incorporation of organic matter either in the form of crop residues or farmyard manures has been shown to improve soil structure (aggregate stability) and water retention capacity, increase the initial and steady infiltration rates and decrease bulk density, resulting in reduction in crust formation and consequent increase in water productivity. Several studies have been conducted to monitor the long term impact of INM, tillage practices and residues application on soil quality indicators and indices at network centers of All India Coordinated Research Project for Dryland Agriculture and at Hyderabad. Study conducted by Hati et al.[15] indicated that an integrated supply of nutrients through organic and inorganic sources could be an effective practice of nutrient management for increasing water-use efficiency and yield of rainfed soybean in Vertisols of central India by improved soil physical conditions through better aggregation, increased saturated hydraulic conductivity, reduced mechanical resistance and bulk density, and enhanced root proliferation of rainfed soybean.

Rainwater and soil moisture conservation practices for *rainfed* soils

During the rainy season, in the cropped fields, about 10 per cent of the rainfall was lost as runoff from black, and about 25 per cent from red soils. Firstly, it was realized that the land needed some kind of vegetal cover to minimize the runoff and soil loss. Secondly, various practices have been recommended for soil and moisture conservation in *rainfed* regions. Some crops such as pearl millet, horse gram and pigeonpea provided cover to the soil, thus resulting in considerable reduction in runoff and soil loss. Deep ploughing, soil stirring and mulching helped to conserve soil moisture. For slope about 1.5 percent, contour bunds with surplusing arrangement were very effective in black soils. Comparison of graded bunds and live bunds revealed that live bund could reduce runoff by about 34 percent compared to sowing across the major slope and soil loss was reduced by about 74 percent. Compared to graded bunds, the runoff was not reduced due to live bund but the soil loss was reduced by 70 percent[16]. In deep black soils with gentle slopes and other sloppy lands surface configuration, such as ridges and furrows, tied ridges and compartments help to hold rain water, increase infiltration, and reduce runoff and soil loss. Various conservation tillage practices viz. ridge and furrow, broad bed furrow, and raised bed and sunken bed of different widths were also evaluated on black soils of low (Prabhani) and high (Jabalpur) rainfall areas to avoid water logging during rainy season. These practices found effective to various extent depending upon topography, crop and rainfall. Painuli and Yadav[2] reported that in sorghum 27.2% yield increased due to ridge and furrow at Jabalpur, and 17.3% yield increased at Prabhani over farmer's practices. Similarly, due to broad bed and furrow 18.3 and 25.2% yield increased in greengram and sorghum, respectively at Prabhani over farmers practices. Raised bed and sunken bed were also found to increase the yield by 5.2 to 55.2 % in various crops (paddy, cotton soybean black gram, pigeonppea, sesame etc.) at Prabhani[2]. Kurothe *et al.*[17] reported that ridge farming tillage, no tilllage and stubble mulch farming tillage reduced runoff by 69.4, 16.2 and 59.6%, respectively compared to conventional tillage. They further reported that the highest average yield of all the crops (pearl millet, cowpea, mustard, pigeonpea and castor) except greengram was recorded under stubble mulch farming tillage.

Surface residue as mulch

There is no doubt that application of the surface management and surface residues improves the soil moisture status and the effect of surface residues impact is more in *rainfed* regions; as these management practices alter the pattern of water entry into the soil. Study conducted by Rao *et al.*[42] reported that application of G*liricidia* in *rainfed* areas improved the water holding capacity and reduced the soil erosion. The studies conducted at CRIDA showed that in *rainfed* situation where only a single crop is grown in a year, it is possible to raise a second crop with residual soil moisture by covering soil with crop residues[18]. These moisture conservation practices improved plant stand, profile water use and yield of *rainfed* chickpea**.** Organic mulches reduced runoff and soil loss. They improve surface soil conditions in two ways. Firstly, by reducing rain drop impact, secondly, by increasing biological activity particularly by termites that build channel and increase the number of continuous tubular pore in the top soil, which facilitated the water entry into the soil. These mulches also retard the formation of surface crust in micro depression or tied furrows and therefore increase the infiltration of water into the sub soil.

Conservation/minium tillage

Conservation tillage appears to be more appropriate under *rainfed* agriculture than zero tillage. Tillage alone without residue retention may not be of much utility in these areas. Sharma *et al.*[19] reported that graded level of sorghum residue application on surface in combination with minimum tillage on long term basis helped in increasing the infiltration rate and available water content in *rainfed* Alfisols soil under sorghum-cowpea rotation. In the *rainfed* hills of north-west India, maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.) is the dominant cropping system. However, *rainfed* wheat suffers from lack of optimum moisture at sowing. Many researchers suggested that mulches and conservation tillage are useful in *rainfed* wheat in mitigating this problem. Acharya *et al.*[20] reported that in case of the wheat shown after the harvest of maize, mulches ((@ 10 Mg ha^{-1} dry weight basis) of weeds like *Lantana camara* (lantana) or *Eupatorium adenophorum* plus conservation tillage resulted in higher moisture (0.06±0.10 m^3 m^{-3}) in the seed-zone when compared to conventional farmer practice.

Addition of clay and tank silt

Many studies in the *rainfed* regions of Aridisols and red Alfisol soils revealed that mixing of the clay in the soil could improve the yield potential of the *rainfed* crops. Application of the 2% clay in red soil sandy loam soils of the Andra Pradesh increased the yield by more than 10 times[2]. Application of tank silt @ 60 t ha^{-1} showed increased available water retention in the soil to the extent of 2% Rao *et al.*[21] in red Alfisol soil of Andhra Pradesh. Other study conducted by Osman,[22] revealed that addition of tank silt @ 50, 100, 150 and 375 tractor loads per hectare improved the available water content by 0.002, 0.007, 0.012 and 0.032 g g^{-1}soil, respectively. The moisture retention has also gone up to support the crop for additional 4 to 7 days, which plays an important role during the period of prolonged dry spells and intermittent droughts. This could be possibly due to the formation of aggregate in light soils which help in retaining more water and nutrient by reducing the percolation due to addition of clay. This technology is viable where fine textured soil is available for application either from ponds or nearby fields.

Addition of absorbent polymers, soil conditioner, natural occuring salts and sealant materials

Addition of absorbent polymers, soil conditioner and natural occurring salts affect water penetration rate, density, structure, compactness, texture, crust hardiness of soil, aggregate anchorage, evaporation, soil infiltration, aeration, size and number of aggregates, soil water tension, available water, soil crispiness and finally cause better water management condition in semi arid soils[23]. The Pusa Hydrogel is evolved specifically to work efficiently in the hot tropical and semi-tropical climate of the country where most other gels fail to perform properly. It works as an anti-drought mechanism and reduces the water requirement of plants. Due to use of Pusa hydrogel, there is a 40 to 70 per cent saving of water. Painuli and Pagliai[24] observed that poly vinyl alcohol and dextran (soil conditioners) improved the soil structure considerably and soils treated with these conditioners produced numerous fine cracks, smaller clods and imparted greater stability against water which is important in agriculture. Application of Krilium (soil conditioner) resulted in a marked increase in the yield of cauliflower due to improvement in soil structural stability which also resulted in increasing the available water through improved infiltration. These enhanced the capacity of the soils to absorb rainfall and decreased runoff, thereby increasing the water storage capacity of the soil. Contradictory to the above soil conditioner, Agrosil LR (soil conditioner) decreased the hydraulic conductivity of sandy soils and improved the aggregation in these soils which lead to an increase in water storage.

The addition of sodium alignite (natural occurring salts) increased the stability of granules but it decomposes rapidly. It needs more research on stabilization of natural and synthetic salts suitable for *rainfed* regions.The percolation loss of water could be reduced by treating the sub surface (below 60 cm depth) with a suitable sealant like hot asphalt emulsion (@14000 l ha^{-1}), Janta emulsion (a product of Burmah shell) and bentonite clay[25]. The practical feasibility of using these sealants is however limited.

Summary

Application of FYM on seed lines as mulch was very helpful in reducing the ill-effects of surface crust on seedling emergence and crop establishment in crust prone sandy loam and loamy sand soils of rainfed regions by increasing soil moisture and reducing soil temperature in the seed zone. Soil compaction and compaction plus clay management technologies were found to be very effective in reducing water and nutrient losses, increasing profile moisture storage capacity and the yield of various crops in highly permeable sandy soils of rainfed regions. Conservation tillage and application of soil conditioner were found to be quite promising and effective management technologies in rainfed areas. Tillage operations with chiseller was effective in breaking the high bulk density in sub-soil layer and resulted in increased water entry and crop yields.

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ROLE OF SOIL CARBON SEQUESTRATION STRATEGIES IN CLIMATE RESILIENT AGRICULTURE

Sumanta Kundu
ICAR-Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad

Introduction

The changing climate leads to increased fluctuations in rainfall and drought, which poses a serious threat to the food security in vulnerable regions (Adger et al., 2003). Regions that are particularly vulnerable are those where adverse effects of climate change intensify environmental threats that result from existing socio-economic and environmental processes. Examples are arid and semi-arid regions where desertification as a result from land-use intensification accelerates through increased drought severeness (Lal, 2004), and rainforests where the negative effects of deforestation and forest degradation are worsened by increased rainfall that results from climate change (Verchot et al., 2007). Adapting agricultural production systems to such changes is one of major challenges of sustainable agriculture. Atmospheric enrichment of GHGs can be moderated by either reducing anthropogenic emissions, or sequestering carbon (C) in plant biomass or the soil. Transfer of atmospheric CO_2 into other pools with a longer mean residence time, in such a manner that it is not re-emitted into the atmosphere in the near future, is called sequestration. Depending on the processes and technological innovations, there are three main types of C sequestration: (i) those based on the natural process of photosynthesis and conversion of atmospheric CO_2 into biomass, soil organic matter (SOM) or humus and other components of the terrestrial biosphere; (ii) those involving engineering techniques; and (iii) those involving chemical transformations (Lal, 2008). The rate of enrichment of atmospheric CO_2 concentration can be reduced by its transfer to other pools by mitigative and adaptive options. Mitigation strategies involve those options that either reduce emissions or sequester C. Emission reduction includes those technologies that enhance energy-use efficiency and involve low-C or no-C fuel sources.

Carbon sequestration

SOM in soils is a strong determinant of soil quality and controls the physico-chemical and biological soil processes. A warming climate and decreasing soil moisture limits the soil functions. One of the important climate smart agricultural practices is reduction of CO_2 emission by restoring soil organic carbon (SOC) pool and improving soil quality which can address both the problems of food security and climate change. Most agricultural soils in India are reported for their low SOC stocks. Changing and uncertain climate may further exacerbate risks of soil degradation by accelerated erosion, secondary salinization, depletion of SOC stock, elemental imbalance and the overall decline in soil quality and productivity. Current database shows that around 121 M ha land has been degraded in the country, of which 68 % is due to water erosion, 20 % by chemical and 10 % by wind erosion. In rainfed situation, long fallow periods, uneven distribution of rainfall, and mono-cropping are the main factors responsible for broader yield gaps. Therefore, maintaining SOC concentration above the threshold level is essential to climate resilient agriculture. Natural processes of C sequestration in terrestrial and aquatic ecosystems (e.g. soils, vegetation, wetlands) contribute to increased biomass, improved soil health and function, including nutrient cycling, water infiltration, soil moisture retention as well as water filtration and buffering in wetlands. Thereby these processes enhance the resilience of ecosystems and the adaptation of these systems to climatic disruptions with the attendant changes in temperature, precipitation and frequency and intensity of extreme events. Most soils under the managed ecosystems contain a lower SOC pool than their counterparts under natural ecosystems owing to the depletion of the SOC pool in cultivated soils. The most rapid loss of the SOC pool occurs in the first 20-50 years of conversion from natural to agricultural ecosystems in temperate regions and 5-10 years in the tropics (Lal, 2001). In general, cultivated soils normally contain 50-75 percent of the original SOC pool. The depletion of the SOC pool is caused by oxidation or mineralization, leaching and erosion. Thus, soil C sequestration implies increasing the concentration/pools of SOC (and SIC as secondary carbonates) through land-use conversion and adoption of recommended management practices (RMPs) in agricultural, pastoral and forestry ecosystems and restoration of degraded and drastically disturbed soils. Formation of charcoal and use of biochar as a fertilizer is another option (Fowles, 2007). In contrast with geological sequestration, which implies injecting CO_2 at a depth of 1–2 km, the SOC sequestration involves putting C into the surface layer at a depth of 0.5-1.0 m using the natural processes of humification.

Technologies and Management practices which influence C sequestration

Green manuring and Green Leaf Manuring (GLM)

Incorporation of green manures adds a lot of fresh, readily degradable material to the soil. The increased production of microbial biomass helps soil aggregation. A soil with better aggregation (aggregate stability) is more resilient in heavy rain storms and is capable of greater water infiltration. Green manures can contribute 60–120 kg N ha^{-1} to the succeeding crop (Srinivasarao et al., 2003). Gliricidia and Tephrosia are two most commonly used green leaf manures. Gliricidia leaves contain 2.4% N, 0.1% P and 1.8% K besides all other secondary and micro nutrients. Gliricidia plants grown on 700 m long bunds can provide about 30 kg N ha^{-1} yr^{-1}. The gliricidia leaf manure applied in between rows can also act as mulch cum manure providing nutrients as well as water conservation during intermittent dry spells. Usually, about 1-2 t h^{-1} leaves can be applied. One tonne gliricidia leaves provide 24 kg N, 1 kg P, 18 kg K, 85 g Zn, 164 g Mn, 365 g Cu, 728 g Fe besides considerable quantities of S, Ca, Mg, B and Mo. Tephrosia (*Tephrosia vogelii*) is another green leaf manure plant. Its leaves and seeds contain high amounts of nutrients, especially N. Many studies showed that Neem (*Azadiracta indica*) and Subabul (*Leucaena leucocephala*) with chemical N fertilizer significantly enhance N uptake and agronomic efficiency. In rice-wheat cropping systems grain yields were significantly greater with green manure of Sesbania (*Sesbania sesban*) incorporated into the soil 30 days after sowing (Yadav, 2004). Application of Gliricidia leaf manuring has increased yields of different rainfed crops in many regions such as that of finger millet in red (Alfisols) soils of Karnataka, groundnut in red soils of Andhra Pradesh, pearl millet in light textured soils of Gujarat, and sorghum in medium to deep black (Vertisols) soils of Maharashtra (AICRPDA Annual Report, 2010). At Bhubaneswar, in acid red and lateritic (Ultisols) soils, grain yield of maize improved from 1.7 to 2.1 Mg ha^{-1} by Gliricidia-GLM equivalent to 20 kg N ha^{-1} (AICRPDA Annual Report, 2007). It is reported that two INM treatments, 2 Mg of Gliricidia loppings+20 kg N and 4 Mg compost+20 kg N can increase the sorghum grain yield by 84.6% and 77.7% over control, respectively. However, the highest SOC concentration (0.74%) was observed in 100% organic treatment (4 Mg compostþ2 Mg Gliricidia loppings). Some of these options of managing nutrients by using farm-based organics can also form a potential component of organic farming.

FYM

FYM supplies all major nutrients (N, P, K, Ca, Mg, S,) necessary for plant growth, as well as micronutrients (Fe, Mn, Cu and Zn). Hence, it acts as a mixed fertilizer (Khan et al., 2010, Dejene and Lemlem, 2012). FYM improves soil physical, chemical and biological properties (Khan et al., 2010). Improvement in the soil structure due to FYM application leads to a better environment for root development (Prasad and Sinha, 2000). FYM also improves soil water holding capacity (Dejene and Lemlem, 2012). The fact that the use of organic fertilizers improves soil structure, nutrient exchange, and maintains soil health has raised interests in organic farming (Khan et al., 2010). Carbon sequestration potential (CSP) and sustainability of gardenpea-french bean cropping system was assessed with farmyard manure (FYM) application vis-à-vis mineral fertilization as recommended NPK (NPK) and integrated nutrient management practices (INM) after six years' cropping in Indian Himalayas (Table 1). The results reveled that application of 20 tons FYM ha^{-1} provided highest C sequestration potential (0.527 Mg C ha^{-1} $year^{-1}$) in soil, application of 5.9 and 8.9 tons FYM ha^{-1} would may substitute NPK and INM, respectively (Mahanta et al., 2013). It seems that FYM may lead to long-term C sequestration in soils and maintain sustainability.

Table 2. Effect of fertilization on selected soil chemical properties and carbon equivalent emission from irrigated garden pea- French bean cropping system after six years.

Treatments[a]	pH	SOC [b] Concentration (g/kg)	SOC amount/Stock (Mg/ha)	CO_2 emission reduction through SOC Stock (Mg/ha)	CO_2 equivalent emission from production of nutrient (kg/ha/yr)	Soil CEC (c mol /kg)
Control	6.11	9.54	20.2	0	0	9.07
FYM -5	6.65	11.88	24.4	15.5	56	11.36
FYM-10	6.72	12.35	25.2	18.4	112	11.92
FYM-15	6.78	12.59	25.5	19.5	168	12.3
FYM-20	6.85	13.21	26.6	23.3	224	13.03
NPK	5.64	11.57	24	13.8	479	10.53
INM	6.3	12.08	24.5	15.7	295	11.8

[a] See Section 2 for treatment details, LSD- Least significant difference, SEM- Standard error of mean.

[b]SOC- Soil Organic Carbon. (Source: Mahanta *et al*., 2013)

Vermicompost

Earthworms are important organisms helping nature to maintain nutrient flows from one system to another and also minimizing environmental degradation. Earthworm population decreases with soil degradation and thus can be used as a sensitive indicator of soil degradation or state of soil health. Earthworms consume various organic wastes and reduce their volume by 40–60%. Each earthworm weighs about 0.5 to 0.6 g, eats waste equivalent to its body weight and produces cast equivalent to about 50% of the waste it consumes in a day. Vermicasts are the main component of vermicompost (Manna et al., 2012). Composts can be used in INM. In a recent field study in India, suggest that 50% N from chemical fertilizer and 50% from vermicompost, with the addition of *Azospirillum lipoferum* and *Bacillus megaterium* var. phosphaticum as biofertilizers applied to rice could increase yields up to 15% compared to the control (receiving 100% RDF-chemical fertilizer) (Jeyabal and Kuppuswamy, 2001).

Tillage practices

The predominant reasons of degradation of soil quality and decline in agronomic productivity include the following: i) erosion of topsoil and the SOC stock associated with the sediments reducing soil fertility, and ii) intensive deep and inversion tillage with moldboard and disk ploughs resulting in a) rapid decomposition of remnants of crop residues further accentuated by high temperatures, b) disruption of stable soil aggregates and aggravating the process of oxidation of entrapped SOC and c) disturbance of the habitat of soil micro flora and fauna and loss of microbial diversity. Recently, reducing tillage technology is gaining acceptance to tackle above described problems. Many literatures around the world are reported that reduced tillage/no tillage useful for sequestering the atmospheric C, which could minimize the emission. A study has been conducted on reduced tillage practices, and across 100 comparisons it was found that soil C stock in NT was lower in 7 cases, higher in 54 cases and equal in 39 cases compared with CT in the 0- to 30-cm soil depth after 5 years or more of NT implementation (Govaerts et al., 2009). These studies were primarily from USA and Canada and some from Brazil, Mexico, Spain, Switzerland, Australia, and China. A meta-analysis found increased soil C in the topsoil (0-10 cm) on conversion of CT to NT but no significant difference over the soil profile to 40 cm due to a redistribution of C in the profile (Luo et al., 2010).

Carbon input and productivity enhancement

Application of manures and other organic amendments with chemical fertilizers is important strategy of SOC sequestration. Several long-term experiments in India have shown that the rate of SOC sequestration is greater with application of nutrient when in integrated manner increases C input and sequestration. The various crop production systems presented (Table 1) shows that maximum input is greater in double cropping system than single cropping annually. For every Mg ha^{-1} increase in SOC stock in the root zone, there was an increase in grain yield (kg ha^{-1}) of 13 for groundnut, 101 for finger millet, 90 for sorghum, 170 for pearl millet, 145 for soybean, 18 for lentil, and 160 for rice (Fig 1). Thus, increasing SOC stock is essential to increasing productivity of rainfed crops in India and elsewhere in the tropics (Lal, 2010; Lal et al., 2003).

Table 1. Mean annual C input, C depletion rate, critical C input (Srinivasarao *et al.*, 2013).

Location/ Production system	Mean annual C input (Mg C ha^{-1} y^{-1})	Critical C input requirement (Mg ha^{-1} y^{-1})
Anantapur (Groundnut)	0.5-3.5	1.12
Bangalore (Groundnut- Fingermillet rotation)	0.3-3.0	1.62
Bangalore (Fingermillet)	0.3-3.1	1.13
Solapur (Winter sorghum)	0.6-3.4	1.10
S.K. Nagar (Pearlmillet-clusterbean-castor)	0.2-1.9	3.30
Indore (Soybean-saflower)	1.9-7.0	3.47
Varanasi (Upland rice-lentil)	1.1-5.6	2.47

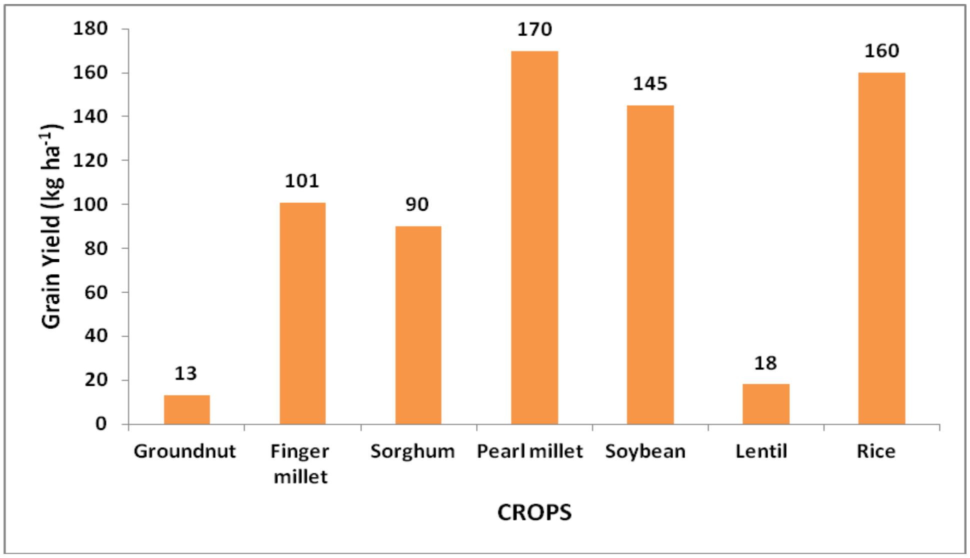

Fig. 1 Increase in crop yield (kg ha^{-1}) for every Mg ha^{-1} increase in SOC stock in the root zone in different rainfed production systems

Cropping systems and SOC sequestration

Total potential of soil C sequestration in India is 39 to 49 Tg yr^{-1} (Lal, 2004c). This is inclusive of the potential of the restoration of degraded soils and ecosystems which are estimated at 7 to 10 Tg C yr^{-1}. The technical potential of adoption of RMPs on agricultural soils is 6 to 7 Tg yr^{-1}. In addition, there also exists some potential of sequestration of SIC, which is estimated at 21.8 to 25.6 Tg C yr^{-1}. Long term manurial trials conducted in arid regions of Andhra Pradesh (at Anantapur) under rainfed conditions indicate that the rate of C sequestration in groundnut production system ranges from 0.08 to 0.45 Mg $ha^{-1}yr^{-1}$ with different nutrient management systems (Srinivasarao et al., 2009a). Under semiarid conditions in Alfisol region of Karnataka, the rate of C sequestration is estimated at 0.04 to 0.38 Mg $ha^{-1}yr^{-1}$ in finger millet system under diverse management practices. Under winter sorghum production system in Vertisol region of Maharashtra (semiarid) the sequestration rate ranges from 0.1 to 0.29 Mg $ha^{-1}yr^{-1}$ with different integrated management options. In soybean production system in black soils of Madhya Pradesh (semiarid), the potential rate of C sequestration is up to 0.33 Mg $ha^{-1}yr^{-1}$ in top 20 cm depth. The TC stock increases with increase in MAP (Srinivasarao et al., 2009b).

Soil water conservation measures

A wide range of soil and water conservation practices (e.g., contour farming, ridge and furrow system, broad bed and furrow system, sunken and raised bed system, conservation furrow, paired row planting, mulching with different materials) are recommended in rainfed regions of India (Das et al., 2011). However, successful soil and water conservation depends on the degree of the adaptability of these practices under site-specific conditions. Water harvesting, effective recycling, and establishment of silt traps at farm levels have shown the benefits of soil conservation, which reduces SOC and nutrient stocks (NAIP, 2011). Effective water harvesting, farm ponds with good crop and soil management practices not only improve farm productivity but also enhance SOC sequestration and reduce the risks of soil degradation (CRIDA, 2012).

Land use systems

The type of land use and management practices has a strong bearing in changing and restoring the SOC stock long with other soil quality parameters. Land use types greatly influence SOC stock through altering the balance between inputs of biomass C and the multiple degradation pathways of its loss largely depend on management activities under each land use system. Some of the strategies (Fig. 2) for enhancement of the concentration soil C

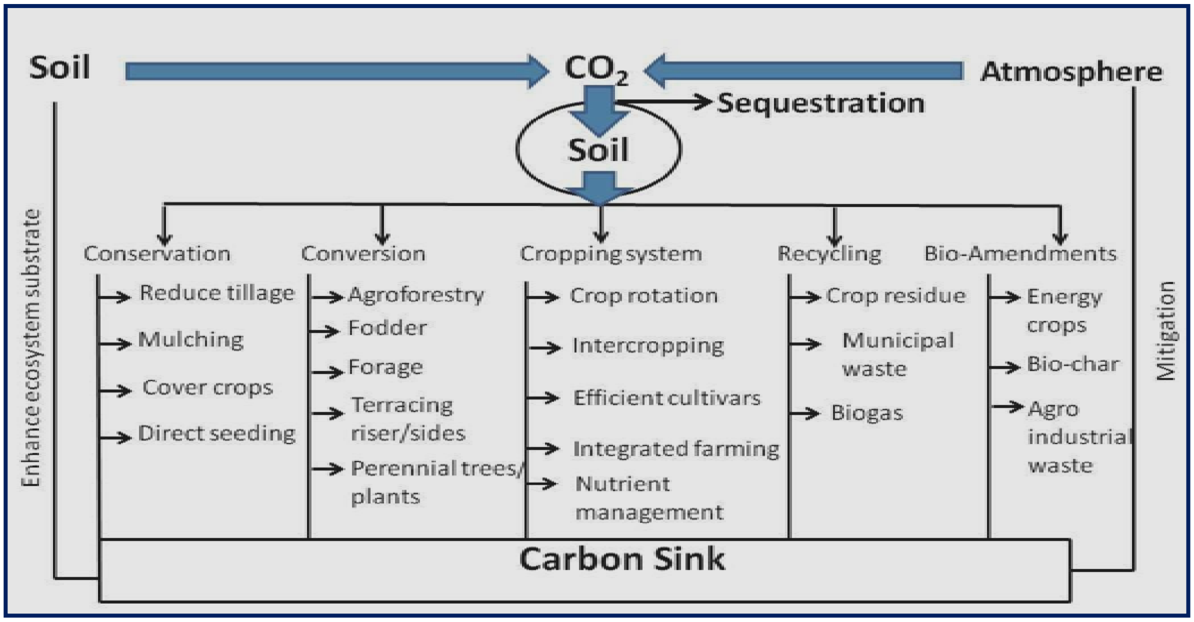

Figure.2. Carbon management options in climate smart agriculture for mitigation (Srinivasarao et al. 2015b)

In India, average sequestration potential in agro-forestry has been estimated to be 25t C per ha over 96 million ha, but there is a considerable variation in different regions depending on the biomass production. Evidence is now emerging that agro-forestry systems are promising management practices to increase above ground and soil C stocks to mitigate greenhouse gas emissions. The carbon sequestration potential of tropical agro-forestry systems in recent studies is estimated between 12 and 228Mg ha^{-1}, with a median value of 95 Mg ha^{-1} (Newaj and Dhyani, 2008). Higher status of soil organic carbon (SOC) was recorded under different alternate land use systems than in agricultural land and fallow land (Reddy, 2002). Among different land use systems, higher status of SOC (t ha^{-1}) was recorded under Agri-silviculture (19.93) followed by silvi-pasture (17.47), Agri-silvi-horti system (17.02) , *L. leucocephala* (15.68), *A. albida* (15.23), *E. camuldulensis* (13.22), *T. gradis* (12.54), *D. strictus* (11.65), *A. indica* (11.43) and agricultural land (9.4) .Carbon mitigation potential was also high (4.23) in Agri-Silviculture system as compared fallow land.

Many agronomic forestry and conservation practices including best management practices leads to net gain in carbon fixation in soil. Soils gaining SOC are also generally gaining in other attributes that enhances plant productivity and environmental quality. In general there is favorable inter play between carbon sequestration and various recommended land management practices related to soil fertility, tillage, grazing and forestry.

Conclusion

The research findings from the ongoing long term application of inorganic fertilizers along with organic manures play a vital role in not only obtain higher crop yields but also to sustain soil fertility and to sequester high amounts of SOC even under arid, semi-arid and sub-humid climates. The economic values of soil C need to be assessed with consideration for both onsite and offsite affects. The dynamics of C sequestration process must be evaluated in the context of local soil and crop attributes. Large area of degraded lands is available for re-vegetation and reforestation of these lands must be given a high priority for C sequestration. To mitigate climate change, there should be policy reforms to encourage environmental sustainability, improve infrastructure and planning related to carbon sequestration research, long term monitoring and large financial commitment. Procedures are needed to be developed for soil C accounting system and policies need to be established that provide incentives for net soil C sequestration at the global scale.

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Soil and fertilizer management practices for reducing the green house gas emissions

J.V.N.S. Prasad and Ch. Naga Jyothi
Central Research Institute for Dryland Agriculture, Hyderabad-500 059

Agriculture sector contributes to global warming primarily through the emission of green house gases (GHG) such as CH_4, N_2O and CO_2. Globally, agriculture, forestry and other land use (AFOLU) sector is a source contributing to 24% of the total GHG emissions (IPCC, 2014) where as in India, various activities of agriculture are contributing upto 17% of the GHG at the national level (INCCA, 2010). Energy consumption in the agriculture sector is the main source of CO_2 emissions. Energy is used in various agricultural operations such as diesel for ploughing, transportation of agricultural produce, water lifting, etc. and electricity consumption for water lifting and irrigation, etc. Various tillage operations directly and indirectly contribute to the carbon dioxide (CO_2) fluxes. Agricultural management practices affect different soil processes, and other ongoing soil decomposition processes, resulting in the conversion of plant-derived carbon to CO_2 (Franzluebbers et al., 1995). Application of inorganic as well as organic fertilizers and different degrees of soil moisture and temperature strongly affect the fluxes of soil CO_2 (Ren et al., 2007). Burning of crop residues is one of the potential sources of GHGs and alternative options such as management of crop residues on the soil surface instead of burning can be of great use in arresting emissions and maintaining soil fertility.

CH_4 is produced in soil during microbial decomposition of organic matter under anaerobic conditions. Rice cultivation contributes up to 21% of the total emissions from the agricultural sector. Burning of crop residues also contributes to the global methane budget. The enteric fermentation in ruminants is another major source of CH_4 emission. The quantum of N_2O emissions are about 13% of the total emissions from agriculture sector. Nitrous oxide is produced naturally in soils through the processes of nitrification and denitrification. Nitrification is the aerobic microbial oxidation of ammonium to nitrate, and denitrification is the anaerobic microbial reduction of nitrate to nitrogen gas (N_2). Nitrous oxide is a gaseous intermediate in the reaction sequence of denitrification and a by-product of nitrification that leaks from microbial cells into the soil and ultimately into the atmosphere.

There is a need to reduce the GHG emissions particularly during the agricultural production process. The emphasis should be on those practices which can reduce the GHG emissions without impacting the agricultural production per se. Focus needs to be on the implementation of farming practices that develop soil health, sustainable nutrient management and encourage environmental sustainability. There are technologies that can reduce GHG emissions. Management practices such as conservation tillage, crop rotation selection or type of fertilizer can promote long-term soil productivity while reducing these emissions.

Management Practices for reducing GHGs

1. Adoption of no-till management system

Farming methods that use mechanical tillage, such as the mouldboard plough for seedbed preparation or disking for weed control, can promote soil C loss by several mechanisms: they disrupt soil aggregates, which protect soil organic matter from decomposition, stimulate short-term microbial activity through enhanced aeration, resulting in increased levels of CO_2 and other gases released to the atmosphere and mix fresh residues into the soil where conditions for decomposition are often more favourable than on the surface. Furthermore, tillage can leave soils more prone to erosion, resulting in further loss of soil C. No-tillage practices, on the other hand, cause less soil disturbance, often resulting in significant accumulation of soil C and consequent reduction of gas emissions, especially CO2, to the atmosphere compared to conventional tillage. There is considerable evidence that the main effect is in the topsoil layers with little overall effect on C storage in deeper layers.

2. Management Practices for reducing Methane

There are a number of feeding practices that will improve livestock production efficiency and at the same time reduce methane emissions.

a) Feeding practices

Methane producing rumen microbes thrive on highly fibrous feeds (eg. mature pasture, tropical grass and hays). This low digestibility diets ferment to a near-neutral pH producing large amounts of hydrogen gas, which the methane-microbes require. In contrast, cereal grain concentrates ferment to produce little hydrogen gas and a highly acidic rumen, both of which are restrictive to methane producing rumen microbes. Ensuring a high quality pasture (i.e. high quality ryegrass rather than Setaria or Paspalum) will cause cows to eat more, produce more, but produce less methane per unit of output. Thus providing animals with the best combination of pasture quality and concentrate feeding will effectively reduce methane emissions from the herd. The above best management practices are entirely consistent with continual efficiency improvements in livestock production.

3. Best Management Practices for reducing Nitrous Oxide

While actual nitrous oxide emissions are relatively small, the abatement potential can be significant through improved fertilizer, soil and animal management. Greenhouse gas emissions are 44% higher with stubble burning of maize residues than where stubble was incorporated into the soil. Clearly this is a best management practices that reduces nitrous oxide emissions, reduces carbon dioxide loss and, although slow, improves soil carbon over time. Both these studies present best management practices that benefit overall farm efficiency and the environment.

From our research to date, the following best management practices are likely to both improve overall nitrogen efficiency and reduce nitrous oxide losses. The best management practices presented below are entirely consistent with current industry best practice for overall nitrogen efficiency and thus present a win-win opportunity.

a) **Source, rate and timing (split) of Nitrogen (N) applications**

1. Nitrate nitrogen sources (ie, ammonium nitrate, potassium nitrate, calcium ammonium nitrate) may result in greater denitrification and leaching than ammonia-based sources of nitrogen (ie, urea, DAP, ammonium sulphate) if applied under cold, wet and waterlogged (soils close to field

capacity or above) conditions. However, ammonia-based sources could lose high amounts of ammonia gas if top-dressed under warmer and windy conditions, especially on alkaline soils.

2. Match crop or pasture demand - Only apply nitrogen when crop or pasture is actively growing and can utilize the nitrogen. Nitrogen is always more efficiently utilized when applied strictly according to growth potential ie, only apply the highest recommended rates when no other limiting factors are restricting yield potential.

3. Warm and waterlogged soils - Avoid high nitrogen rates on waterlogged soils, particularly if soil temperatures are above 10 °C, as this will increase denitrification losses. Denitrification is highest under anaerobic soil conditions, particularly when these conditions are coupled with warmer soil temperatures.

b) Coated/chemically treated fertilizers

There are a number of coatings that can be applied to nitrogen fertilizers that will greatly reduce nitrous oxide losses directly from fertilizer. However, these coatings have no effect on losses of nitrogen derived from legumes and urine. At this stage these products are too expensive to justify their commercial use in agriculture and require further research to evaluate performance.

1. **Nitrification inhibitors -** This coating inhibits the conversion of ammonia to nitrate in the soil, thus reducing the chance of both nitrate leaching and denitrification loss. An example of such a compound is dicyandiamide (DCD), proven effective in many studies.

2. **Controlled release -** A range of polymer-coated / impregnated fertilizer products are available, releasing their nitrogen according to the predicted crop growth pattern. This controlled release significantly improves fertilizer efficiency. However, if the onset of conditions favorable to denitrification coincides with nitrogen release form the coated fertilizers, denitrification may still result albeit at a lower rate than would have occurred using conventional forms of fertilizer nitrogen.

C) Crop and Pasture Management

1. **Reduce fallow -** During the fallow period the soil continues to break down organic soil nitrogen into nitrate (mineralisation followed by nitrification) but there is no crop to utilize this nitrate, as a result this nitrate is susceptible to nitrate leaching and denitrification loss following heavy rainfall.

2. **Cover crops -** Where possible use non-leguminous cover crops to use residual nitrate nitrogen in soil such as in cotton cropping.

3. **Water availability and use –** Excess availability of water creates conditions for runoff and waterlogging which can contribute to denitrification or leaching of nitrates.

4. **Other nutrients -** If there are other nutrients limiting the growth potential of the crop or pasture, nitrogen fertiliser use will be less efficient leading to greater loss potential.

5. **Subsoil limitations -** Such as transient salinity, sodicity, acidity, restrict the ability of crops to effectively utilize soil nitrogen. Nitrogen inputs (from either fertiliser or legumes) should be adjusted (reduced) to reflect the true yield capacity of crops where subsoil limitations are present.

Table 1. Summary of mitigation options to reduce GHG emissions

CO_2	CH_4	N_2O
• Use of low- or no-till practices • Residue retention • Use of biochar • Enhancing energy use efficiency	• Irrigation management • Use of cultivars with low CH_4 production • Crop residue management	• Improved fertilizer use efficiency • Use of nitrification inhibitors • Split application of nitrogen • Use of leaf colour chart for better timing of fertilizer

Significant reductions in GHG emissions can be achieved within the agricultural sector through the implementation of current best management practices that are entirely consistent with improving the efficiency of agricultural production. These best management practices represent a clear win-win opportunity. A number of options are being developed to improve dietary efficiency in animal production systems and nitrogen cycling efficiency in grazing and cropping systems. These options need to be commercially assessed before their large scale dissemination and use.

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Energy efficiency in agriculture to minimize GHG emissions

I.Srinivas and C.R. Thyagaraj
Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, Telangana

Introduction:

The agriculture sector has at its core the production process for foodstuff (e.g., grains, fruits and vegetables, meat, fish, poultry, and milk), and non-food vegetable products of economic value (e.g., tobacco, jute, hemp). However, the sector also comprises or has close links with processes that take place before and after this core production process, such as fertilizer production, post-harvest processing, and transport of foodstuff. Defined broadly, the agriculture sector has as its primary goal the delivery of food on the table for the population or for export. Despite the relative importance of this sector to economic activity and employment in the Developing countries, agricultural energy use tends to be small compared to that in industry or transport.

Farm Power availability and energy utilization in dryland agriculture is far less than that of irrigated agriculture. The output –input energy ratio is generally higher (3 to 8) in dryland crop production than that of irrigated crops(1to 3). How ever, higher output-input ratios alone will not mean anything, without obtaining higher yields per unit area.

Analysis of the trend of direct energy use in production agriculture since 1970 indicates a sharp decline in the contribution of animate energy since early eighties due to continuous decrease in use of draught animal in crop production activities. Enhanced use of diesel and electricity has dominated the energy scenario. When the total direct energy consumption is compared with change in good grain productivity during the same period, the rate of increase of energy consumption far exceeded the growth of agricultural productivity.

It is observed from the Livestock census report 2003 that there is a decrease in working animal population by 6.89 % when compared to the year 1997 which is an alarming signal for draught power availability for agricultural use. The other way tractorization is taking place at rapid level at 7 % (around 35 lakh by 2005) growth rate since last 3 years which means that the fuel consumption for agriculture sector will also increase accordingly. The increase in number of tractors every year is reducing the number of country ploughs at village level because of which many working bullocks are under utilized.

Percentage of contribution of different power sources to Total power availability in India

Share of total power	1971-72	81-82	91-92	01-02	05-06
Agricultural worker	15.11	10.92	8.62	6.49	5.77
Draught animal	45.26	27.23	16.55	9.89	8.02
Tractor	7.49	19.95	30.21	41.6	46.70
Power tiller	0.26	0.33	0.40	0.54	0.60
Diesel engine	18.11	23.79	23.32	19.86	18.17
Electrical motor	13.77	17.78	20.90	21.26	20.73
Total Power KW/ha	0.295	0.471	0.759	1.231	1.502

(source: Power availability in Indian Agriculture 200, CIAE, Bhopal

From the above table it is very clear that the animal and human power sources are almost phasing out from the Indian agriculture as far as there share is concerned which warns us to develop a separate power package for the dryland areas where most of the operations are to be done on timeliness basis to make use of available moisture in the soil. Apart from this the electricity share for Indian agriculture is increased from 18.64% (82-83) to 30 %(2004) may expected to rise by 40 % by 2025 which means the steep rise in electric motors, left irrigation schemes and electric driven farm machinery.

One of the major constraints to agricultural production and productivity in drylands is the inadequacy of farm power and energy. The average farm power availability needs to be increased from the current 1.15KW/ha to atleast 2.0kw/ha to to assure timeliness and quality in field operations, practice heavy field operations like sub-soiling, chiseling, deep ploughing, summer ploughing etc.

Compared to irrigated agriculture, dryland agriculture lacks artificial irrigation. In addition to being thirsty of water, the drylands are hungry for lack of nutrients. The present consumption of fertilizers too, for dryland crops was found to be less than 50 % of the recommended doses. In addition , the dryland agriculture is weak, in the sense, power availability and energy use in dryland agriculture is far less. When the power availability to Indian agriculture was 0.92 Kw/ha in 1991, the same to dryland agriculture was 0.45 Kw/ha.

Farm Machinery and Power Scenario: Use of tools, implements and machines for agricultural operations is termed as farm-mechanization. The interjection of improved tools, implements, machines and associated management practices between farm workers and agricultural materials such as soil, water, plants, animals and fish, their produce and by-products is called farm mechanization (Alam, 1999). Farm mechanization helps in increasing production, productivity and profitability in agriculture by achieving timeliness in farm operations, and bringing precision in metering and placement of inputs. It also reduces avoidable input losses by increasing utilization efficiency of costly inputs such as seed, chemical, fertilizer, irrigation, water etc. and efficient use of animal and commercial energy.

Farm power density and India's position in World Agriculture: Farm power available per hectare of land is one of the important indices of progress in production and productivity. India has 2.5 and 11.7 per cent of geographical and arable area of the world, respectively. In absolute terms they are 329 and 162 Mha. In area and arable area India occupies seventh and second position amongst the countries of the world. With 21.8 per cent of irrigated area of the world or 59 M ha of area irrigated, India occupies first rank amongst area under irrigation. Rainfed agriculture in India, extends over 97 Mha or nearly 67 per cent of the net cultivated area. India has 16 million population which is 17 per cent of the world population and is placed second in the world. With about 215, 181 and 383 million heads of bovine, sheep and goat and chicken it occupies first, third and seventh rank, respectively in the world. It produces 230 and 16 Mt of cereals and pulses, or about 11.1 and 27 per cent of the world production and occupies third and first rank respectively. It has 1.55 million of tractors or 6 per cent of the world's 26.3 million tractors and occupies third position in the world.

Average size of agricultural holdings in India is 1.6 ha and is very less as compared to the highest average holding of 3590 ha in Australia. Aargentina, Uruguay, Canada, New Zealand and USA has 470,285, 242, 216 and 197 ha of holdings. Japan, Korea, Nepal, Ethiopia and

Tanjania are some of the countries having lesser average size of agricultural holdings i.e. 1.2, 1.1, 0.9, 0.8 and 0.2 ha respectively. In India, 60 per cent of economically active population is dependent on agriculture, as compared to world average of 45 per cent. In developed countries like UK, USA, Canada, Japan and Australia lesser persons i.e., 1.8, 2.2, 2.4, 4.3 and 4.7 per cent population is dependent on agriculture. Myanmar, China, Afghanistan and Sudan with 68, 67 and 62 per cent respectively are some of the countries having more population dependent on agriculture.

Tractors world wide registered a growth rate of 1200 per cent from 2.2 million to 26.3 million between 1980 and 1998. Growth rate of tractors and harvesters / threshers in India also is high to an extent of 404 per cent from 0.38 million to 1.55 million units during the some period.

Cropping intensity in India has increased from 111.1 to 136.1 per cent during 1950-51 to 1998-99, net irrigated and rainfed agriculture area was 57.03 and 8557 Mha. In about 18.52 and 29.5 M ha of irrigated and rainfed area, sowing was done more than ones and hence the gross areas were 75.55 and 115.07 Mha, respectively. Total gross cropped area was 190.62 Mha (Agricultural Research Data Book 2003). Average land holding was about 0.39, 1.43, 2.76, 5.9 and 17.33 ha respectively, under marginal small, semi-medium, medium and large farm categories. Diverse farm mechanisation scenario prevails in the country due to size at farm holdings (average farm holding size 1.6 ha) and socio-economic disparities. Gyanendra Singh (2002) reported that Indian agriculture continues to be dependent upon human agricultural workers (207 million in 1996-97) and drought aniaml pair (DAP) power (35 million pair). Present tractor population is about 2 million with an annual production 0.25 million. Tractor availability on an average is about 70 ha/tractor and drought animal is about 4 ha/pair. Farm power availability from all sources (animate and mechanical power) is shown in Table 1.
Tillage (15.6%), irrigation (80.5%), threshing (47.8%) and rice-milling (73%) operations by and large utilise mechanical power. (Percentages in parenthesis indicate extent of dominance of mechanical power).

Today, India has one of the most dynamic farm machinery industry producing annually 2.5 lakh tractors. The largest in the world, 10,000 power tillers, 2.5 lakh seed drills, 4.0 lakhs power threshers. 45 lakhs sprayers and dusters, 7.0 lakh pumpsets, 850 combines besides a host of other farm equipment (Alam, 1999). The number of land holdings is increasing and holding size is steadily declining average holding size has declined from 203 ha in 1970-71 to 1.6 ha in 1990-91. Marginal and small farms (below 2 ha) numbering 78 per cent of the total holdings account for only 32 per cent of the area cultivated, whereas 20 per cent of medium farm (2-10 ha) account for 50 per cent as the cultivated area 1.7 per cent large farms (above 10 ha) account for 18 per cent of the cultivated area. Therefore its agricultural mechanisation, strategy there is need for a paradigm shift.

But while on record average holdings may be reducing due to the lack of inheritance, operational holdings are emerging large amounts for mechanized farming as evidenced in Punjab and Haryana.

RELATIONSHIP BETWEEN FARM POWER AND CROP YIELDS; Randhawa et al (1982) reported that farm power availability per hectare of land in developed countries like Japan, USA, UK, France, Germany and Italey are 3.7, 1.1, 1.2, 2.4, 4.1 and 1.7 kw/ha. The same figures for developing countries like Bangladesh, Egypt, India and Pakistan are 0.23, 0.64, 0.29 and 0.32.

Total farm power availability has increased from 0.25 kw/ha in 1951 with animate power contributing 97 per cent to 1.15 kw/ha in 1997 with animate sources contributing only 23 per cent, mechanical sources 43 per cent and electrical 34 per cent. The availability of draft animals is reducing, thus short falls have to be met mostly through electro mechanical power sources. There is a definite and positive relationship between farm power availability and farm production levels. Data given in Table-2 reveal that farm production levels increased along with increase in the power availability. However, the rate of increase in yield per hectare showed a gradual decline. Hence, there is a good scope in India for substantially increasing the crop yields even with incremental increase in the levels of power availability provided such power sources are utilised to optimum levels with good energy management (Thyagaraj, 1992).

Human labour : About 222.5 million persons work as labour force in agriculture, mainly to carryout field operations like sowing, interculture, weeding, harvesting and threshing.They contribute about 11.1 million kw of power or about 0.08 kw/ha during 2001.

Draught animal : Indian agriculture has about 72.3 million draught animals.(2001) On an average one draught animal pair (DAP) is available for every 7 to 10 ha of cultivated area in drylands, while one pair is available for every 3-5 ha of land in irrigated agriculture. Desirable density is about one DAP for every 3-4 ha. For a crucial field operation like sowing, if the field capacity of sowing device is taken as 0.1 ha/hr, time required for completing sowing operation in a village would be atleast 7 to 8 days. Under receding moisture condition of dryland agriculture, sowing should preferably be completed in one day. This is a constraint, because some sowings would have been done in inadequate soil moisture conditions or would be waiting for next event of rainfall. In either of the cases delay in sowing operation takes place. This effects badly the crop performance and yields. One medium size bullock pair develops on an average 0.5 kw of power.This source contributed about 0.12 kw/ha of cultivated area.

Tractors : Tractor use is gradually increasing in India and are available in 20 to 75 HP ranges. About 2.6 million tractors are in use in our country. Tractor density is high in Punjab, Haryana and Western UP and under irrigated areas in the rest of the country. About 2.5 lakh tractors are produced and sold annually. In the Punjab belt, tractor density is about one for every 5 to 7 ha, while in Telangana belt of AP it is one for every 50 to 100 ha. Desirable density is about one for every 15 ha.

Motors / engines : Electric motors and diesel engines numbering around 9.52 and 6.47 million are used mostly to lift / pump water for irrigating the crops both from tube wells / open wells and canals. Engines are also used in plant protection and threshing equipment. Self propelled combine harvesters, winnowers are recent additions (since 20 years) to Indian agriculture.

Experience has shown that there is a definite and positive relationship between farm power availability and farm production levels. Farm power availability to individual farms varies from 0.1 to 6 kw/ha depending upon the economic status and need of the farmer. Farm power availability of 1 to 1.5 kw/ha seems to be comfortable in completing all field operations in time and hence would help in attaining good crop yields. Therefore, there appears to be good scope in India to substantially increase the crop yields even with incremental increase in the levels of power availability, provided such power sources are utilized to optimum levels with good energy management. Improved farm implements and machinery with higher capacities and improved cultivation practices can play a vital role in achieving this target. Low power availability can considerably delay a farm operation there by decreasing the yields. This could be overcome either by increasing the power availability, or by utilizing the existing power sources more efficiently. Field operations like tillage, sowing, fertilizer application, interculture, weeding, spraying and dusting (of plant protection chemicals), harvesting and threshing are very important and timeliness of these operations enhances and assures good crop yields. Delay in field operation has adverse effect on crop husbandry and results in reduction of yields from 10-80%. Availability of matching farm implements having high capacity is another factor. Timely availability of other inputs like seed, fertilizer, chemicals along with proper crop management are also equally important in crop production

From above review, it was found that the mechanization play a vital role increasing the food production at the targeted rate. Now the following subheads deal with the specific machinery and methods of mechanization for different operations. As the energy use in agriculture contributes to the emissions in agriculture, it is highly essential to manage the resources optimally to reduce the cost of cultivation and GHG emissions. These are discussed below:

Energy needs of Agriculture and its impact on emissions:

Agriculture requires energy at all stages of production. Energy is used by agricultural machinery (e.g., tractors and harvesters), irrigation systems and pumps, which may run on electricity, diesel, or other energy sources. Energy is also needed for processing and conserving agricultural products, transportation, and storage. In that respect, it is a critical factor in adding value in the agricultural sector. Indirect energy use occurs mainly through the production and application of mineral fertilizers and chemicals required to improve crop yields. In many cases, electricity and fuel use tends to be inefficient because of price subsidies, and thus mitigation options may offer a significant potential for improving efficiency and reducing GHG emissions from this sector.

Mitigation options available for energy conservation in agriculture sector:

Potential mitigation options for agricultural energy use are described below. While some of the options are not yet available for widespread implementation, or need more scientific and economic analysis before their applicability can be assessed, they are also presented since they might become feasible later on. The main near-term option likely to be of interest for GHG mitigation is efficiency improvement in irrigation. The use of various renewable sources of energy for agricultural applications (e.g., wind-driven pumps, solar drying, diesel engines powered with mostly gasified biomass) have been tested on a limited scale and may be of interest in some cases. (Agricultural residues may also be used for meeting energy demands outside the agriculture sector - e.g., for cogeneration in agro-processing industries.)

- Reduce energy use for irrigation.

  Irrigating crops often requires considerable amounts of electricity or diesel fuel. Reducing energy consumption for irrigation while providing the desired service may be accomplished through use of more efficient pump sets and water-frugal farming methods. To improve the efficiency of irrigation pump sets, a number of technical measures are available. These include: use foot valves that have low-flow resistance; replace undersized pipes and reduce number of elbows and other fittings that cause frictional losses; use high-efficiency pumps; select pumps better matched to the required lift characteristics; use rigid PVC pipes for suction and delivery; operate pumps at the recommended RPM; select prime mover for the pump (i.e., electric motor or diesel engine) matched to the load; select an efficient diesel engine or motor for the application; schedule and perform recommended maintenance of the pump and the prime mover; and ensure efficient transmission of mechanical power from the prime mover to the pump.

- Increase the efficiency of non-pumping farm machinery:
  Energy use for traction for cultivation, sowing, weeding, harvesting, and other operations can be reduced through use of more efficient equipment or by minimizing the need for traction through low-tillage agriculture.
- Switch to lower-carbon energy sources:
  Options in this category include wind- and photovoltaic-powered pumps, enhanced solar drying, and use of biofuels instead of fossil fuels in various applications where heat is required.
- Reduce input of chemical fertilizers:
  The two basic ways of reducing the input of chemical fertilizers are to target fertilizer application better and to substitute organic or microbial fertilizers for chemical fertilizers. Reduced demand for chemical fertilizer lowers energy use in the chemical industry. There have been limited studies in developing and transition countries on reducing the intensity of chemical fertilizer inputs through improved application or use of organic fertilizers so assessing the potential impact of this option is difficult.
- Use conservation tillage systems:
  Conservation tillage practices store carbon in the soil through retention of vegetative matter (crop residue). Since most conservation tillage practices reduce the number of trips across a field needed to grow and gather a crop, total energy required to grow a crop is reduced.
- Improve efficiency of post-harvest drying and storage:
  Various agricultural products are subjected to drying or cold storage before they are sent to market. The efficiency of these processes can generally be improved through use of better equipment and proper maintenance.
- Reduce post-harvest food grain losses:
  Assuming that food needs are being met, use of storage methods impervious to pests and rodents can reduce the need for crop production, thereby saving the energy that would be used in that production.

Energy efficient Technologies presently using in agriculture:

1. Conservation Agriculture:

In the context of mitigation of GHG’s, conservation tillage, defined, in general terms, as the reduction of soil tillage intensity in combination with the maintenance of crop residues on the soil surface, can play a decisive role. Nothing is more important to humanity than reliable food production, but the mechanization and intensification of traditional tillage based systems has exacerbated major environmental problems, because:

1. Conventional tillage is fossil-energy intensive process, which also accelerate s oxidation of soil organic matter
2. Conventional tillage buries residue, which is the surface soil's natural protection against erosion by wind and water
3. Tillage and traffic cause subsurface degradation, reducing soil biological activity and promoting root zone water logging, which converts crop nutrients into nitrous oxide and methane-both damaging the greenhouse gases.

Conservation tillage was originally developed to halt the soil erosion caused by traditional tillage based agriculture. The first conservation agriculture system identified soil tillage as a major problem, and replaces this with herbicide and other weed control measures. It is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. It is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes. Conservation Agriculture is characterized by three principles which are linked to each other, namely:

- Continuous minimum mechanical soil disturbance.
- Permanent organic soil cover.
- Diversified crop rotations in the case of annual crops or plant associations in case of perennial crops.

Advantages of Conservation Agriculture:

Conservation Agriculture, understood in this way, provides a number of advantages on global, regional, local and farm level:

- It provides a truly sustainable production system, not only conserving but also enhancing the natural resources and increasing the variety of soil biota, fauna and flora (including wild life) in agricultural production systems without sacrificing yields on high production levels. As CA depends on biological processes to work, it enhances the biodiversity in an agricultural production system on a micro- as well as macro level.
- No till fields act as a sink for CO_2 and conservation farming applied on a global scale could provide a major contribution to control air pollution in general and global warming in particular. Farmers applying this practice could eventually be rewarded with carbon credits.
- Soil tillage is among all farming operations the single most energy consuming and thus, in mechanized agriculture, air-polluting, operation. By not tilling the soil, farmers can save between 30 and 40% of time, labour and, in mechanized agriculture, fossil fuels as compared to conventional cropping.
- Soils under CA have very high water infiltration capacities reducing surface runoff and thus soil erosion significantly. This improves the quality of surface water reducing pollution from soil erosion, and enhances groundwater resources. In many areas it has been observed after some years of conservation farming that natural springs that had dried up many years ago, started to flow again. The potential effect of a massive adoption of conservation farming on global water balances is not yet fully recognized.

- Conservation agriculture is by no means a low output agriculture and allows yields comparable with modern intensive agriculture but in a sustainable way. Yields tend to increase over the years with yield variations decreasing.
- For the farmer, conservation farming is mostly attractive because it allows a reduction of the production costs, reduction of time and labour, particularly at times of peak demand such as land preparation and planting and in mechanized systems it reduces the costs of investment and maintenance of machinery in the long term.

Limitations of Conservation Agriculture:

The most important limitation in all areas where conservation agriculture is practiced is the initial lack of knowledge. There is no blueprint available for conservation agriculture, as all agro-ecosystems are different. A particularly important gap is the frequent dearth of information on locally adapted cover crops that produce high amounts of biomass under the prevailing conditions. The success or failure of conservation agriculture depends greatly on the flexibility and creativity of the practitioners and extension and research services of a region. Trial and error, both by official institutes and the farmers themselves, is often the only reliable source of information.

Conservation agriculture technologies and machinery used:

Conservation agriculture Technologies	Machinery Used	Potential Benefits
Laser leveler	Land leveller, Laser land leveller	Cuts water use; fewer bunds and irrigation channels; better soil nutrient distribution; less leaching of nitrates into groundwater; more efficient tractor use (reduced diesel consumption); increased area for cultivation.
Zero-tillage	Zero till drill, Planter with double disc coulters	Less labor required; soil physical structure is maintained (reduced nutrient loss, soil health maintained); less water required; avoids large cracks in soil after dry periods; can keep previous crop’s residue in field for mulch (if appropriate drill seeder is used for seeding); subsoil layer is not compacted by tractors (compacted subsoil impedes root growth).
Crop residue mulch	Heavy ripper, motorized rotary hand-held mower, Animal traction knife roller, Tractor mounted knife roller, Shredder, Combine harvester with straw chopper	Increases soil water-holding capacity, increases soil quality, reduces weed pressure, avoids burning.
Dry seeding	Rolling punch injection planter, Drill seeder	Less water required; less labor required (especially at peak transplanting time); post harvest condition of field is better for succeeding crop; deeper root growth (meaning better tolerance of dry conditions, better access to soil

		nutrients).
Drill seeder	Dibbler, Animal/Tractor drawn precision planter	Precise seeding (reduced seed rate); applies fertilizer and/or herbicide simultaneously with seed (increased input efficiency); seeds through previous crop's residue; incorporates previous crop's residue into soil (adds to soil fertility).
Green manure (*Sesbania*)	Knife Slasher, Straw chopper	Fast early growth suppresses weeds; after herbicide treatment, it acts as mulch (reduces evaporative water loss; adds soil organic matter plus nutrients—especially nitrogen—to the soil).
Crop diversifi cation (raised seedbeds, intercropping)	Bed planter, Raised bed and furrow planter	Two to three crops grow simultaneously (e.g., rice, chickpea, pigeon pea, maize); increased income; increased nutritional security.

Hence, it is recommended to adopt the energy efficient technologies for sustainable agriculture for the benefit of the farming community in India.

(e) Combine harvesting.

Sickles are widely used for harvesting. These are easily available at low cost in the villages but their output.

Table 11. Trends in Growth of Power Operated Agricultural Machinery (in hundred)

Power source 1971- 1976- 1981- 1986- 1991- 2000-72 77 82 87 92 01,
Power Sprayer/Duster 448 851 1239 1853 2771 3110, M.B. & Disc Plough 573 925 1429 2392 4989 12431, Disc harrow 556 1292 1892 3574 5456 28814, Cultivator 815 1766 3150* 5956 11558 28115, Seed drill/seed fert., Drill 246 640 1606 2777 7301 27405, Planter 85 244 305 443 643 1090, Thresher 2058 4841 10250 13638 13793 30900
Table 12. Trends in growth of harvesting and threshing machinery (in hundred)

Power source 1971-72 1991-92, Tractor Powered Combine Harvesters 3.5 61.5, Self Propelled Combine Harvesters 4.5 35.0, Stationary Threshers 2058 13793, Wheat 1825 10757, Paddy 136 1353

Use of Polymers for Improving Water and Fertilizer Use Efficiency in Different Crops Grown in Rainfed Areas

K. Sammi Reddy
Head, Division of Resource Management, Central Research Institute for Dryland Agriculture, Santoshnagar, Saidabad P. O., Hyderabad – 500 059 (A. P.)
Email: ksreddy_iiss39@yahoo.com

1. Introduction

The problem of inefficient use of rain & irrigation water by crops is most important in rainfed agriculture in semiarid and arid regions. Application of water-saving super absorbent polymers (SAP) in to the soil could be an effective way to increase both water and nutrient use efficiency in crops (Lentz et al. 1998). When polymers are incorporated with soil, it is presumed that they retain large quantities of water and nutrients, which are released as required by the plant. Thus, plant growth could be improved with limited water and nutrient supply (Gehring and Lewis, 1980).

Super absorbents were introduced to the markets in early 1960s, by the American company, Union Carbide (Dexter and Miyamoto, 1995). The product absorbed water thirty times as much as its weight and did not last long and was sold to greenhouse retail markets. Soon it was determined that the product was unsuccessful in market because of its low swell (high cost per unit of water held) and short life (Joao et al. 2007). In fact materials having the capacity to absorb water 20 times more than their weights are considered as a super absorbent (Abedi-Koupal and Sohrab, 2004). But due to development of more cross linked polymers with high water holding capacity (400 times & in some cases even up to 2000 times of their weight) and comparatively low cost than earlier ones has rejuvenated interest on the use of polymers in agriculture. This paper reviewed the key aspects of use of polymers in agriculture, highlighting current research in this field and the future needs in India.

2. Types of polymers

Both water soluble and insoluble polymers have been marketed for agricultural use. Water-soluble polymers do not form gels and are used as soil conditioners. These include poly (ethylene glycol), poly(vinyl alcohol), polyacrylates and polyacrylamides. Water soluble polymers were developed primarily to aggregate and stabilize soils, combat erosion and improve percolation, and by doing so, improve crop yields on very droughty and structureless soils. Although some of these materials (polyacrylates and polyacrylamides) use the same chemical building blocks as the gel-forming polymers, soil conditioners possess what chemists refer to as linear chain molecular structure and do not form water-absorbing gels.

Insoluble water-absorbing polymers were first introduced for agricultural use in the late1970s and early 1980s. Depending on the type of polymer and the conditions during synthesis, water absorbing polymers have the ability to absorb up to 1,000 times (or more) of their weight in pure water and form gels. Because of their tremendous water-absorbing and gel-forming abilities, they are referred to as super absorbents or hydrogels. There are three main groups of hydrogels, (i) Starch-graft co-polymers, (ii) Polyacrylates, (iii) Acrylamide-acrylate co-polymers.

3. Effects of polymer application on soil and crop

(i) Effect of application of polymers on soil moisture storage and water use efficiency

When polymers are incorporated into a soil or soilless medium, they retain large quantities of water and nutrients. These stored water and nutrients are released as required by the plant. Thus, plant growth could be improved, and/or water supplies conserved. It has been reported that a 171% to 402% increase in the water retention capacity is recorded when polymers were incorporated in coarse sand (Ekabafe et al. 2011). It has been reported that increased water retention capacity attributed to polymer addition significantly reduced irrigation frequency (Flannery and Busscher, 1982) and the total amount of irrigation water required. Regarding the available moisture, the best results were obtained with application of PR3005A polymer in levels of 4 and 8 g/kg in loamy soils. The moisture amount in this situation was increased by 2 to 4 times respectively (Ghaiour, 2000). Sivapalan (2006) stated that the retained water in sandy soil was equal to 23 and 95% with application of polymer at 0.03 and 0.07% of its weight, respectively. Johnson (1984) estimated that applying super absorbent to sandy soils cause an increment in water holding capacity from 171 to 204%.

(ii) Effect on Soil and its Erosion

Super absorbent polymers affect water penetration rate, density, structure, compactness, texture and crust hardiness of soil, aggregate anchorage (Helalia and Letey, 1989**)** and evaporation (Tayel and El-Hady, 1981), soil infiltration and aeration, size and number of aggregates, soil's water tension, available water, soil crispiness[18] and finally cause better water management practices in soil.

Non-cross-linked anionic polyacrylamides (PAM, containing <0.05% AM) having very high molecular weight ($12\text{-}15x10^{6}$ g mol^{-1}), have also been used to reduce irrigation-induced erosion and enhance infiltration. Its soil stabilizing and flocculating properties improve runoff water quality by reducing sediments, N-dissolved reactive phosphorus (DRP), chemical oxygen demand (COD), pesticides, weed seeds, and microorganisms in runoff.

(iv) Effect on Crop growth

Super absorbent polymers cause improvement in plant growth by increasing water holding capacity in soils (Boatright et al. 1997) and delaying the duration to wilting point in drought stress (Gehring and Lewis, 1980). Water conservation by gel creates a buffered environment being effectiveness in short term drought tension and losses reduction in establishment phase in some plant species. Totally, proficiency in water consumption and dry matter production are positive plant reactions to super absorbent application (Woodhouse and Johnson, 1991). Poly (ethylene oxide) hydrogel, polyacrylamide hydrogel and cross-linked poly (ethylene oxide)-co-polyurethane hydrogel were attempted to alleviate the plant damage that resulted from salt-induced and water deficient stress (Shi et al. 2010).

4. Factors affecting super absorbent polymer performance

Although many researchers have documented increased water-holding capacity, reduced irrigation frequency, greater water use efficiency, enhanced infiltration rates, reduced compaction tendency and increased plant performance with hydrogel use, others have failed to see such benefits (Nus, 1982). Perhaps a critical assessment of the variables that affect hydrogel performance will help explain why. These variables include polymer type, rate and grind size, method of application, salinity of the soil solution, effects of specific ions, soil texture, temperature, intended use etc.

(i) Type of polymer

As sated earlier, there are three main groups of hydrogels. They differ widely in their total absorbency, time needed to hydrate, structural integrity and longevity in the soil. Starch-graft co-polymers may take up to a few hours to hydrate completely. However, starch graft co-polymers do not possess the gel strength or longevity that cross linked acrylamide-acrylate co-polymers do (Grula and Huang, 1982). Activity of starch-graft co-polymers is usually limited to a single season, whereas, the cross linked acrylamide-acrylate co-polymers remain active for five to seven years or longer.

In addition to differences between polymer groups, there are hydrogels within a group that may differ substantially. For instance, some cross-linked acrylamide-arylate co-polymers can absorb only 30-40 times their weight of deionized water compared to a more common 400x absorbency factor for many cross-linked arylamide-acrylate co-polymer hydrogels. However, these lower absorbing co-polymers are less affected by salinity than their higher-absorbing counterparts.

(ii) Particle size of polymer

Water absorbing polymers are available in various particle sizes, from powders to coarse granules greater than 2 mm in diameter. The effect of powders versus coarse granules on root zone characteristics such as oxygen diffusion rate and water absorption may be very different. The aim is to amend the soil to substantially increase the water-holding capacity without decreasing the ability for gaseous exchange. If a continuous layer of powder is applied, gas exchange to the roots may be severely reduced. Research that compares powders to fine and coarse-grade granules for their ability to affect gaseous exchange is badly needed.

(iii) Soil texture

Potential benefit of polymers on water storage also depends on the soil texture. Coarse textured soils with large pores tend to retain less water than fine textured soils. Thus, the amount of water that may be retained by incorporating a polymer would be greater in coarse textured soils than in fine textured soils. The bulk density of loamy and sandy soils reduced with polyacrylamide (PAM) addition compared to the control while there was a small increase in bulk density of clayey soil. Conversely, porosity increased with increasing PAM rates for clay loam and sandy soils. However, macro pore size increased in clay soil while it decreased in clay loam and sandy loam soils (Table 1) (Uz et al. 2008). Available water contents of loamy and clay soils showed highly significant increase (108% and 105%, respectively) with the highest 0.67% PAM rate applied due to increase in water content at Field Capacity (FC) and decrease in water content at Wilting Point (WP). Meanwhile, plant available water content of sandy soil increased by 55% since water content at WP increased.

Table 1: Effect of application of different rates of PAM on bulk density and porosity of different soils

Soil property	Soil type	PAM Rates (% by weight)					
		0	0.03	0.10	0.17	0.33	0.67
Bulk Density	Loam	1.48	1.48	1.46	1.45	1.40	1.41
	Clay	1.39	1.38	1.39	1.38	1.41	1.42
	Sandy loam	1.50	1.49	1.49	1.47	1.46	1.39
Porosity	Loam	0.44	0.44	0.45	0.45	0.47	0.47
	Clay	0.48	0.48	0.48	0.48	0.47	0.46
	Sandy loam	0.44	0.44	0.44	0.44	0.45	0.48

Source: Uz (2008)

(iv) Salt concentration in water and soil solution

Johnson (1984) reported that water holding properties of polymers significantly affected by nature and dissolved salts concentration in water of irrigation. Saline water reduces absorption and conservation of water. Akhtar et al. (2004) evaluated effect of water kind on amount and rate of absorption and reported that the maximum time for absorption with distilled water, tap water and saline water were 7, 4 and 12 hr, respectively and the amount of absorption in 1 hr was measured as 505, 212 and 140 g/g , respectively. Increase in water salinity in amount of more than 2.5 dS m^{-1} caused reduction in polymer effectiveness in loamy sandy soils and the plants irrigating with 5 dS m^{-1} used 42% more than that of with 1.6 d S m^{-1} (Bhat et al. 2009). Among various NO_3^- containing salts, hydration of a cross linked polyacrylamide was inhibited most by the presence of Al^{3+}. Similarly, divalent cations (Ca^{2+} and Mg^{2+}) had a greater inhibitory effect on polymer expansion than did monovalent cations (NH_4^+, Na^+, and K^+). The effect of NH_4^+ based salts on polymer expansion (where the cation remained constant but the anion changed) was much less, indicating that the source of cation has a much greater effect on polymer hydration than does the source of anion.

(v) Rate of application of polymers

Polyacrylamide (PAM) rates applied to soil may need to be adjusted based on soil properties, slope, and type of erosion targeted. Older PAM formulation required hundreds of kilograms of PAM per hectare. However, PAM with newer longer-chain polymers is more effective even in lower rates (Wallace and Wallace, 1986). Many researchers found that application of 20 kg ha^{-1} PAM prior to sprinkler irrigation increased infiltration rates and reduced runoff and erosion (Stern et al. 1992).

In some cases, overusing of hydrogels causes reverse results, because it reduces soil air followed by filling vacant spaces and gel swelling. There are many reports of no effect or low effect of gels in overused application of them in soil in growth indices of plants. The main reason as mentioned is due to occupation of many vacant spaces of soil resulting in sever soil ventilation (Abedi-Koupai and Mesforoush, 2009). Sarvas et al. (2007) in an experiment on *Pinus sylvestris* L. seedlings observed that by over using of super absorbent in soil; plants were more likely to exposure to Fusarium diseases and mostly perished. They suggested that some investigation needs to be carried out to find out the most suitable amount of hydrogel in different situation and plant species.

Application of 28 kg water absorption polymer (Bhagiratha) per hectare along with recommended rates of fertilizers to pigeon pea maintained higher soil moisture level in sandy loam soil at different growth stages of crop and produced higher seed yield and nitrogen uptake by 12 and 10%, respectively as compared to control (only fertilizers) (Mondal, 2011). Use of 0.75% (w/w) water soluble polymers with 50% Attainable Moisture Depletion (AMD) to tomato in sandy loam soil produced the highest yield (59.6 t/ha) and maximum water use efficiency (153.6 kg/m^3) as compared to other levels of polymer application (0, 0.25, 1.25 and 1.75%) (Lakshmi, 2011). Application of carboxymethyl cellulose at 2% and 4% rate with 5 tonne compost/ha resulted in increase of maize yield by 25 and 34%, respectively over the untreated sandy soil. The combined effect of both soil conditioners on water and nutrient use efficiency were better than that of their sole application (Table 2).

Table 2: Effect of compost (C) and /or carboxymethyl cellulose (CMC) on marketable yield, water and fertilizers use efficiency by maize crops

Treatment	Rate of application	Yield (kg/ha)	Water use efficiency (kg/m^3)	Fertilizer Use Efficiency (kg grain/unit of added nutrient)		
				N	**P**	**K**
Untreated soil	0	1230	15.24	10.3	82	25.6
CMC 1	2%	2673	16.68	22.3	178	55.7
CMC 2	4%	3010	17.03	25.1	201	62.7
Compost (C1)	5 tonne/ha	2543	15.72	21.2	170	53.0
CMC1+C1	2% + 5 tonne/ha	2997	18.41	25.0	200	62.4
CMC2+C1	4% + 5 tonne/ha	3070	20.07	27.5	220	68.8
l.s.d. (P=0.05)		24.6	-	-	-	-

Source: Ali (2011)

(vi) Method of application of polymers

The performance of the gel on plant growth depends on the method of application as well. It was shown that spraying the hydrogels as dry granules or mixing them with the entire root zone is not effective (Flannery and Busscher, 1982). Better results seemed to be obtained when the hydrogels are layered, preferably a few inches below soil surface. However, generalizations should be avoided when interpreting results as a number of factors such as types of gel, particle size, rate of application, and type of plant has to be taken into consideration.

(vii) Biodegradation of polymer

The persistence of a particular polymer in the soil may affect its usefulness as a device to delay the release of water and nutrients. In general, naturally occurring polymers are readily degraded by soil microorganisms, while synthetic polymers are more resistant to biological breakdown. Many of the natural polymers contain chemical bonds that may be broken through common enzymatic hydrolysis in soils. The synthetic polymers typically demonstrate much greater resistance to biological attack, since soil microbes have not yet developed the polymer-specific enzymes required for rapid decomposition.

(viii) Temperature

In soil, polyarylamide polymers degrade at rates of at least 10% per year as a result of physical, chemical, biological and photochemical processes (Tolstikh et al. 1992). Intense UV radiation in the open is known to increase the breakdown rates. Bhat et al. (2009) investigated the effects of high temperatures on the performance of PAM polymers using ornamental plant (Concarpus lancifolius) in sandy soil under three temperature regimes, viz., Variable Ambient Temperature (VAT, daily maximum and minimum temperatures ranging from 33-49^{o}C and 25-35^{o}C, respectively), Environment Controlled Greenhouse (GH, daily maximum and minimum temperatures ranging from 27-41^{o}C and 20-35^{o}C, respectively) and indoor temperature regimes (LAB, daily maximum and minimum temperatures ranging from 21-26^{o}C and 20-24 ^{o}C, respectively). The plants grown at 0.4% PAM required 33.8, 38.1 and 30.7% less water than control (no PAM) in VAT, GH, LAB conditions, respectively. The reduced effectiveness of polymers in the VAT regime to a large extent may be related to their degradation due to high temperature and light intensity (Tolstikh, 1992).

5. Conclusions and Future Directions

The review of literature shown that determination of amount of gel for the best performance is influenced by many factors including, climate, substance type (chemical composition and forming method), soil type (Texture, structure and chemical properties), plant species etc. Thus, it is recommended that studies have to be carried out to determine the most suitable amount of hydrogel for each species of plant, climate and substance, individually. In India, very little research work has been done on polymers comparatively. The rate of application of polymers recommended by different polymer suppliers varies from 2.5 kg/ha to 60 kg/ha depending upon type of polymer and crop. Another issue is the longevity of polymers in soils, some polymers are being recommended every year and some other are recommended with 3-5 years of frequency due to their longer longevity in soils. Therefore, systematic field studies under arid and semi-arid conditions of India are needed to develop appropriate rate, frequency and method of application of different polymers to various crops and to assess economics of use of different polymers. It is also essential to determine the duration of effectiveness of the polymers in the soil for economizing their use in agriculture.

There is a need to assess the effect of application of polymers on fertilizer efficiency along with water use efficiency in various crops under variety of soil conditions and different nutrient management systems (such as fertilizers alone, integration of fertilizers and organic manures and only organic manure application). The effect of different methods of application of polymers such as seed treatment, soil application (Broad casting, dibbling, deep placement, row application, wet patch application, etc), root dipping needs to be evaluated on establishment of crops and their growth in dryland areas which is very critical for farmers livelihood.

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Role of biochar as an organic amendment in INM

G Venkatesh, Ch Srinivasa Rao and K.A.Gopinath
Central Research Institute for Dryland Agriculture, Santosh Nagar, Hyderabad

Introduction

Global warming and a fast-growing world population intensify the need to develop solutions for our future food needs (Mathews, 2008). Idea of using biochar as a tool for countering climate change and improving soil health is a recent development, yet its origins extend back to the discovery of Dark Earths, or Terra Preta de Indio (Portuguese for "Black Earth of the Indians"). Biochar appears to be one promising source of renewable and stable carbon to increase the rate of carbon sequestration in soil. Current availability of unused surplus residues in India is estimated at 120-150 million tons / annum. Of this, about 93 million tons of crop residues are burned in each year, these unused residues are valuable resources for production of biochar (Srinivasa Rao *et al.,* 2013). *Terra preta* soils provide information and inspiration for agricultural communities for use of biochar as an organic amendment in Integrated Nutrient Management.

Biochar

Biochar is the carbon-rich solid product, produced by thermal decomposition of organic matter under limited supply of oxygen (O_2) or oxygen-free environment, and at relatively low temperatures (<700°C) through a process called pyrolysis (Lehmann *et al.,* 2006). Biochar is not a pure carbon, but rather, mix of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S) and ash in different proportions (Masek,2009). The central quality of biochar and char that makes it attractive as a soil amendment is its highly porous structure, potentially responsible for improved water retention and increased soil surface area.

Bio-char production technologies

Thermo chemical processes for biomass conversion into biofuels and other bio-based products include pyrolysis, carbonization and gasification (Masek, 2009). Biochar can be produced from a number of methods. The ancient method for producing biochar was the "pit" or "trench" method (Odesola *et al.,* 2010). The common processes include slow and fast pyrolysis, and the most successful approach for high-yield biochar production is via slow pyrolysis. Under slow pyrolysis, a biochar yield between 25 - 35 % can be produced (Hussein *et al.,* 2015); fast pyrolysis processes aim at production of bio-oil and the amount of biochar formed is nearly 12 % of the total biomass (Cheng *et al.,* 2012). The cook stove, earth mound kilns and drum kilns are the traditionally used for biochar production in India. Number of biochar kiln has been designed, developed and used for making biochar from the crop residue and forest biomass in India (Srinivasa Rao *et al.,* 2013; Venkatesh *et al.,* 2015).A summary of biomass conversion processes is presented in Fig. 1. At the instant of burning, the biomass carbon exposed to fire has three possible fates.

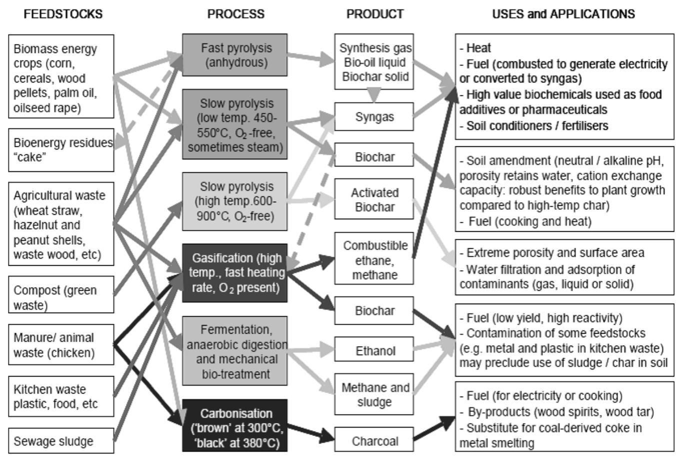

Fig. 1. Summary of pyrolysis processes in relation to their common feed stocks, typical products, and the applications and uses of these products

Critical factors for maximizing the benefits from biochar

Quality of feed-stock biomass

Different types of biomass can produce biochar: crops and forest residues, municipal authority green waste, paper mill waste, sawmill waste, piggery waste, poultry waste and even human waste. All biochar types are beneficial. All biochar increase soil surface area because of the enormous numbers of micro-pores present and thus they work as soil conditioners. They also bind nutrients and prevent their leaching into ground water; they provide microhabitats for micro-organisms and thus help enhance nutrient availability to plants (Lehmann *et al.* 2006). In situations such as desertified land, or even the degraded agricultural lands of India, South Africa and Australia, the benefits can be transforming. But, all types of feed-stock biomasses are not equally good for various types of nutrients. Nutrient types and amounts vary with the biomass used. The higher the amounts of nutrients in a feed-stock biomass, the richer in nutrients are the biochar. The biochar from garden organic waste and poultry and piggery waste are different; poultry and piggery wastes have higher amounts of N and P. A study conducted in Australia by Chan *et al.* (2007) shows that biochar produced from poultry manure has higher electrical conductivity, N, P and pH values than that from garden organic waste (Table 1). These analyses highlight the fact that the more nutrient-rich the organic waste, the greater the benefits from the biochar.

Table 1. Impacts of different biochar on soil properties

Feedstock	Activated	pH	EC dS/m	C %	Total N%	Total P%	Min. N (mg/kg)	Extractable P (mg/kg)
Garden organic	Yes	9.4	3.2	36	0.18	0.07	<0.5	400
Poultry manure	Yes	13	14	33	0.9	3.6	2.5	1800
Poultry manure	No	9.9	5.6	38	2.0	2.5	2.4	11600

Source: Chan *et al*. (2007).

Optimum biochar production temperature

High cation exchange capacity (CEC), carbon levels and higher soil surface areas are some of the properties of better quality biochar. The higher the temperatures of the pyrolysis, the greater are the CEC and surface area of biochar. But, this outcome is compromised in two ways: 1) low carbon levels; and 2) additional handling costs of small-sized biochar (Lehmann, 2007). High-temperature pyrolysis reduces the carbon percentage of biochar, which results in lower carbon sequestration and the other benefits of biochar are also reduced.

Quantity of biochar

What rate of biochar application results in the most beneficial outcome? The answer depends on many factors such as the type of biomass used, the degree of metal contamination in the biomass, the types and proportions of various nutrients (N, P, etc.), and also on edaphic, climatic and topographic factors of the land where the biochar is to be applied. Research suggests that even low rates of biochar application can significantly increase crop productivity assuming that the biochar is rich in nutrients which that soil lacks (Winsley,2007). In the case of piggery and poultry manure biochar, the biochar works both as an organic fertilizer and soil conditioner with agronomic benefits observed at low application rates (10t/ha) (Chan *et al.* 2007). Application to soils of higher amounts of biochar may increase the carbon credit benefit; but, in nitrogen-limiting soils it could fail to assist crop productivity as a high C/N ratio leads to low N availability (Lehmann and Rondon, 2006). Crop productivity benefits of higher biochar application rates can be maximized only if the soil is rich in nitrogen, or if the crops are nitrogen-fixing legumes. Therefore, application of biochar to soils in a legume-based (e.g. peanut and maize) rotational cropping system, clovers and lucernes is more beneficial. Biochar application rates also depend on the amount of dangerous metals present in the original biomass. The chance of bio-magnification also depends on the amount of a given metal in the soil.

Soil carbon level

The soil carbon level of the area where biochar is to be applied is another serious concern. A 10-year study where charcoal was prepared, mixed into the soil and left undisturbed under three contrasting forest stands in northern Sweden, found a substantial increase in soil bacteria and fungi. As a result, there was mineralization (decomposition) of native soil organic matter with accelerated emissions of CO_2 (Wardle *et al.* 1998). This revealed that biochar application in carbon-rich soils could partially offset the GHG benefits. Therefore, to maximize the overall benefits of biochar, it should be applied to carbon-poor soils. Biochar application on Indian and South African agricultural soils could be more promising as 25% of South Africa and 45% of India's cultivated lands are degraded (Hatrack, 2008).

Soil types and soil moisture

A major attraction of biochar is that it increases water quality and plant available water capacity (PAWC). In a dry country such as Australia and India, where water quantity and quality is extremely variable, this would be a significant benefit. The soil type, anywhere, will ultimately determine the soil water benefits of biochar. Soil type has a significant influence on PAWC. Although biochar addition increases the water holding capacity and plant available moisture in sandy soils, there is no guarantee that it will increase the available water in loam and clay soils (Table 2). Because it is so porous, charcoal has a high surface area with increased micro pores and improves the water holding properties of sandy soils – increases their PAWC. But, in loamy soils, no changes are observed; and in clayey soil, the available soil moisture decreases with increasing charcoal additions, probably through the hydrophobicity of the charcoal (Glaser *et al.* 2002). Therefore, biochar soil water benefits are maximized in sandy soils and thus there are enormous benefits of biochar in cropping areas where the opportunity cost of water is very high such as the sandy soils of the Western Australian wheat belt and water scarce soils of India.

Table.2. Effects of biomass derived char on percentage of available moisture in soils on a volume basis

Soil	0% biochar	15% biochar	30% biochar	45% biochar
Sand	6.7	7.1	7.5	7.9
Loam	10.6	10.6	10.6	10.6
Clay	17.8	16.6	15.4	14.2

Source: Glaser *et al.* (2002).

Soil pH and soil contamination

Soil pH is an important factor for plant growth for various reasons: some plants and soil micro-biota prefer either alkaline or acidic conditions; some soil-borne diseases are more common when the soil is alkaline or acidic; and, nutrient availability in soils depends on soil pH. Most macronutrients are available in neutral soils. But, inappropriate use of nitrogenous fertilizers, the removal of crop residues, the leaching of N and the presence of calcium sulphate ($CaSO_4$) parent material, has resulted in soil acidity being a major soil problem worldwide . Acid soils enhance soil contamination, as they increase concentrations of Al and Fe cations in the soil, which decrease the available symbiotic micro-organisms needed for effective tree growth (Shuji *et al.* 2007). In order to neutralize acidic soils, farmers apply thousands of tonnes of lime to farm soils at great expense. In addition to this direct cost, the production, packaging, transportation and application of lime emits significant amounts of GHGs (Maraseni, 2008).

Biochar application method

Biochar application methods have a substantial impact on soil processes and functioning. Biochar application methods must be based on extensive field testing. Various methods of biochar application in soil, were mixing the biochar with fertilizer and seed, applying through no till systems, uniform soil mixing, deep banding with plow, top-dressing, hoeing into the ground, applying compost and char on raised beds, broadcast and incorporation, mixing biochar with liquid manures and slurries (Hussein *et al.,* 2015).

Biochar application rates

Availability and type of crop residue, nature of biochar, application rate, soil type, crops to be applied, labour, time, climatic and topographic factors of the land, and the preference of the farmer may determine to employ one-time application of large quantity or frequent application of smaller quantity biochar (Venkatesh *et al.,* 2015). Past studies have found that rates between 5 to 50 t/ha have often been used successfully (Lehmann and Rondon, 2006).

Biochar for ameliorating soil health

Numerous studies have reported on the beneficial impacts of biochar addition on soil health improvement and GHG emissions reduction which are of critical importance in tropical environments in combating climate change and to improve soil health directly and indirectly. The incorporation of biochar into soil alters soil physical properties like bulk density, penetration resistance, structure, macro-aggregation, soil stability, pore size distribution and density with logical implications in soil aeration, wettability of soil, water infiltration, water holding capacity, plant growth and soil workability; positive gains in soil chemical properties include: retention of nutrients, enhances cation exchange capacity and nutrient use efficiency, decreases soil acidity and increases the number of beneficial soil microbes. A brief review about these interactions is presented in table 3.

Several authors (Amonette and Joseph, 2009; Brownsort,2009 and McLaughlin,2010) also report that biochar has the potential to: (i) increase soil pH, (ii) decrease aluminum toxicity, (iii) decrease soil tensile strength, (iv) improve soil conditions for earthworm populations, and (v) improve fertilizer use efficiency. The combined application of biochar and inorganic fertilizer has the potential to increase crop productivity, thus providing additional incomes, and reducing the quantity of inorganic fertilizer use and importation. Steiner *et al*. (2008) reported that application rate of biochar @ 5 t per ha decreased fertilizer needs by 7%. Biochar has an even greater ability than other soil organic matter to adsorb cations per unit carbon (Sombroek *et al*. 1993). In contrast to other organic matter in soil, biochar also appears to be able to strongly adsorb phosphate, even though it is an anion, although the mechanism for this process is not fully understood. These properties make biochar a unique substance, retaining exchangeable and therefore plant available nutrients in the soil, and offering the possibility of improving crop yields while decreasing environmental pollution by nutrients. Thus, biochar application could provide a new technology for both soil fertility and crop productivity improvement, with potential positive and quantifiable environmental benefits, such as carbon trading.

Table 3. The effect of biochar additions on soil health and GHG emission under different soil types

Soil type	Biochar source	Rate of biochar addition (t ha^{-1})	Impact of biochar addition on soil health and GHG emission	Reference
Anthrosol	Wheat straw	10 and 40	SOC increased by 57 %, total N content was enhanced by 28 % in the 40 t ha^{-1} without N fertilization; Total N_2O emissions decreased by 40-51 % and 21-28 %, respectively in biochar amended soils; Emission factor (EF) was reduced at 40 t ha^{-1}.	Afeng et al. (2010)
Sandy	Green cuttings	1, 10 and 40	Increased CEC, exchangeable K, total N, available P at biochar addition of 10 t ha^{-1}; 10 and 40 t ha^{-1} of biochar increased the water holding capacity of the sandy soil by 6 % and 25 %	Glaser et al. (2014)
Calcareou	Rice husk and	30, 60	Decreased soil bulk density, increased	Liang et

s	shell of cotton seed	and 90	exchangeable K and water holding capacity at 90 t ha^{-1}	al. (2014)
Silty loam	Oak wood	7.5	Reduced soil bulk density by 13 % and increased soil-C by 7 %; Cumulative N_2O emission was decreased in the biochar-amended soil (by 92 %)	Mukherjee et al. (2014)
Sandy loam	Maize stover, Pearl millet stalk, Rice and Wheat straw	20	Maize biochar enhanced the soil available N and P; Wheat biochar increased the soil available K; Rice biochar being relatively labile in soil fuelled the proliferation of microbial biomass.	Purakayastha et al. (2015)

Crop productivity

Several workers have reported that biochar applications to soils have shown positive responses for net primary crop production, grain yield and dry matter (Spokas *et al.* 2009). The impact of biochar application is seen most in highly degraded acidic or nutrient depleted soils. Low charcoal additions (0.5 t ha^{-1}) have shown marked impact on various plant species, whereas higher rates seemed to inhibit plant growth (Ogawa *et al.* 2006). Crop yields, particularly on tropical soils can be increased if biochar is applied in combination with inorganic or organic fertilizers (Glaser *et al.* 2002).

Table 4. Summary of experiments assessing the impact of biochar addition on crop yield

Authors	Study outline	Results summary
Yamato *et al.* (2006)	Maize, cowpea and peanut trial in area of low soil fertility	*Acacia* bark charcoal plus fertilizer increased maize and peanut yields (but not cowpea)
Chan *et al.* (2007)	Pot trial on radish yield in heavy soil using commercial green waste biochar (three rates) with and without 'N'	100 t ha^{-1} increased yield x3; linear increase 10 to 50 t ha^{-1} - but no effect without added N
Rondon *et al.* (2007)	Enhanced biological N_2- fixation (BNF) by common beans through bio- char additions. Colombia	Bean yield increased by 46% and biomass production by 39% over the control at 90 and 60 g kg^{-1} biochar,

		respectively.
Kimetu *et al.* (2008)	Mitigation of soil degradation with biochar. Comparison of maize yields in degradation gradient cultivated soils in Kenya.	doubling of crop yield in the highly degraded soils from about 3 to about 6 tons/ha maize grain yield

Biochar to counter climate change

Biochar has the potential to counter climate change because the inherent fixed carbon in raw biomass that would otherwise degrade to greenhouse gases is sequestered in soil for years. In recent years the use of surplus organic matter to create biochar has yielded promising results in sequestration of carbon. Lehmann *et al.* (2006) estimated a potential global C-sequestration of 0.16 Gt yr^{-1} can be achieved from biochar production from forestry and agricultural wastes. In India, biochar from residues of maize, castor, cotton and pigeon pea can sequester about 4.6 Mt of total carbon annually in soil, making it a carbon sequestering process (Venkatesh *et al.,* 2015). A number of studies have reported on environmental benefits of biochar additions which will reduce emission of non-CO_2 greenhouse gases from soil that could be due to inhibition of either stage of nitrification and / or inhibition of denitrification, or promotion of the reduction of N_2O; increases CH_4 uptake from soil (Rondon *et al.,* 2006).

Constraints to adopt biochar systems

With limited studies in different soil type, climatic zone and land use situations, it is difficult to predict the agronomic effects. Due to the heterogeneous nature of biochar, cost of production of biochar for research and field application is likely to remain a constraint until commercial-scale pyrolysis facilities are established (Sparkes and Stoutjesdijk, 2011). Some of the practical constraints on use of biochar in agricultural systems were ; once applied to soil, remains permanent, unavailability of enough biochar, dry biochar on soil surface is liable to wind erosion, response of local communities to adopt biochar systems (Adtiya *et al.,* 2014); unavailability of farm labour, higher wage rates for collection and processing of crop residue, lack of appropriate farm machines for on-farm recycling of crop residue and inadequate policy support / incentives for crop residue recycling (Srinivasa Rao *et al.,* 2013; Venkatesh *et al.,* 2015) .

Conclusion

Biochar production from farm wastes and their injection into farm soils as organic amendment has a very promising potential for the development of sustainable agricultural systems in India. There is significant availability of non-feed biomass resources in the country as potential feedstock for biochar production. However, to promote the application of biochar as a organic amendment in INM, research, development and demonstration on biochar production and application seem to be very vital.

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Agroforestry and Its Role in Natural Resource Management and Conservation in Rainfed Areas

Dr. G.Rajeshwar Rao
Principal Scientist (Agroforestry), CRIDA, Santoshnagar, Hyderabad

Introduction

Agroforestry is a relatively new name given to an approach to cultivation, which has been used by many farming communities all over the world, in many different ways. It is a collective name for land use systems in which woody perennials are grown in association with herbaceous plants (crop, pastures) or livestock, in a spatial arrangement, a rotation, or both. There are usually both ecological and economic interactions between the tree and other components of the system. The agroforestry model is unique as it focuses on assisting farmers in creating a situation where they are managing their own farmers and natural resources including livestock throughout the year in a sustainable productive way, and making them less dependent on outside labour and forest areas and in the process generate income to the farmers throughout the year. As different components are included in the model, a congenial microclimate would be developed for better growth, thus negating the short-term wide fluctuations in weather conditions.

There are a number of definitions of agroforestry. But, the most commonly used definition is "Agroforestry is a collective name for land use system in which woody perennials (tree, shrubs etc.) are grown in association with herbaceous plants (crops, pastures) or livestock, in spatial arrangement, a rotation or both; there are usually both ecological and economic interactions between the trees and other components of the system" (Lundgren, 1982).

In general there are 4 or 5 basic sets of components which are managed by man in all agroforestry system. Structurally, the system can be grouped as:

1. Agrisilviculture system
2. Agrihorticulture system
3. Silvipastoral system
4. Agri-silvipastoral system
5. Other or specialized systems

On the basis of nature of components the following are common agroforestry systems found in different agro-ecological regions of India:

1. Agrisilviculture (trees + crops)
2. Boundary plantation (tree on boundary + crops)
3. Block plantation (block of tree+ block of crops)
4. Energy plantation (trees + crops during initial years)
5. Alley cropping (hedges + crops)
6. Agrihorticulture (fruit trees + crops)
7. Agrisilvihorticulture (trees + fruit trees + crops)
8. Agrisilvipasture (trees + crops + pasture or animals)
9. Silvi-olericulture (tree + vegetables)
10. Horti-pasture (fruit trees + pasture or animals)
11. Horti-olericulture (fruit tree + vegetables)
12. Silvi-pasture (trees + pasture/animals)
13. Forage forestry (forage trees + pasture)

14. Shelter-belts (trees + crops)
15. Wind-breaks (trees + crops)
16. Live fence (shrubs and under- trees on boundary)
17. Silvi or Horti-sericulture (trees or fruit trees + sericulture)
18. Horti-apiculture (fruit trees + honeybee)
19. Aqua-forestry (trees + fishes)
20. Homestead (multiple combinations of trees, fruit trees, vegetable etc).

Various forms of Agroforestry

The **shifting cultivation-** a traditional agroforestry system is in vogue since ages. Shifting cultivation in India is practiced in 48 districts of 7 north-eastern hill region states, Andhra Pradesh and Orissa and occupy 2.28 million ha (Anonymous, 1997). Due to the increasing demographic pressure, the fallow period became drastically reduced and system degenerated, resulting in heavy soil erosion and decline in fertility and productivity of soils. The important common feature of the shifting cultivation is growing of mixed crops after partial or complete removal of vegetation. In the north eastern India, many annual and perennial crops with diverse growth habits are being grown having sparsely distributed trees on hilly lands. A farming system approach with agroforestry based integrated watershed management has been advocated as an alternative to shifting cultivation. ***Taungya*** **cultivation:** thepractice consists of land preparation, tree planting, growing agricultural crops for 1-3 years, and then moving on to repeat the cycle in a different area. Teak (*Tectonagrandis*), *Eucalyptusglobulus, Acaciamearnsii*, and *Pinus* plantations have been established by the forest department in the states of Kerala, West Bengal, Uttar Pradesh, and to a limited extent in Tamil Nadu, Andhra Pradesh, Orissa, Karnataka, and in the northeast hill region in the earlier century. **Home Gardens:** are intended primarily for household consumption and there is intimate association of woody perennial with annual and perennial crops, and invariably livestock within the compounds of individual houses, with the whole crop-tree-animal unit being managed by family labour. Plantation crops coconut, arecanut, cacao, coffee, and black pepper are the dominant components of many home gardens of the humid tropics. Banana, papaya, mango, guava, custard apple and jackfruit are common fruit plants. In spite of very small average size of the management units, homegardens are characterized by high species diversity and usually 3-4 vertical canopies. The energy and nutrient requirement of people is fulfilled mainly through the products of these gardens. Another important feature of these gardens is that the production for home consumption occurs throughout the year. Apart from 1.33 million ha under homegardens in Kerala, there are homegardens in the states with coastal belts and north-eastern states. **Scattered trees on farm:** The practice of cultivating agricultural crops under scattered trees on farm is quite old. Trees are grown/maintained for various purposes such as shade, fodder, fuelwood, fruit, small timber, vegetables and medicinal use. Some of the agroforestry practices are very extensive and highly developed in some agro-ecological regions of India. For example, growing of *Prosopis cineraria* and *Zizyphusmauritiana* in arid areas, *Acacia nilotica* in Indo-Gangetic plains, *Grewiaoptiva* and other fodder trees in the Himachal Pradesh and Uttarakhand, *Eucalyptus globulus* in the southern hills of Tamil Nadu and *Borassus flabellifer* in peninsular coastal regions. **Trees on farm boundaries:** Tree which are planted in agricultural fields are often grown on farm boundaries. In northern parts of India particularly in Haryana, Punjab and Uttarakhand, *Eucalyptus* and poplarsare commonly grown along field boundaries or bunds of paddy fields. Other trees which are grown as boundary plantations or live hedge include *Acacia nilotica,Dalbergia sissoo* and *Prosopis juliflora*. Farmers of Sikkim grow bamboo (*Dendrocalamus*) all along irrigation channels. In Coastal areas of Andhra Pradesh *Borassus* is most frequent palm. In Andamans farmers grow *Gliricidia sepium*, *Jatropha,Ficus, Ceiba pentendra, Vitex trifoliata,* and *Erythrina indica* as live hedges. At many places *Agave* and many Cacti are grown as common live fence. Many of the boundary plantations also help as shelter belts and wind breaks particularly in fruit orchards. In Bihar *Dalbergia sissoo* and *Wendlandia* are most common species in boundary plantations. *Casuarina equisetifolia* is extensively planted on field bunds and along sandy coastal areas in Orissa. **Block plantations:** as woodlots amidst agricultural fields is a common practice in many parts of India. Now, this practice is expanding fast due to shortage of fuelwood and demand of poles or pulpwood for paper industry. For example, bamboo poles are in great demand for orange orchards in Nagpur area. *Eucalyptus* and Poplar for paper and plywood industries. Wood lots of *Casuarina equisetifolia, Leucaena,* Bamboo, *Populus deltoides, Eucalyptus tereticornis,Pterocarpus santalinus, and Dalbergia sissoo* have become popular in many parts of the country. The driving interest for such a practice is mainly cash benefits. Many such plantations under social forestry are a source of employment for the land less farmers.

Agroforestry systems essentially involve a perennial component to impart stability in production from farmlands. Perennials are known for drought tolerance or avoidance characteristics and can withstand late onset or early withdrawal of monsoon and prolonged dry spells that are frequent in drylands.

Network research carried out in India revealed that alternative land use involving perennials (tree/crop, grass shrub or a combination of both) has advantages and can conserve natural resources and increase productivity (Osman, 2003). Some of the advantages of perennials are:

- They can thrive in relatively resource-poor soils.
- Provide continuous vegetative cover to the soil and thus substantially control erosion caused by both wind and water.
- Amelioration of microclimate.
- Provide good quality green fodder, which is in short supply to support livestock.
- Protect the environment and upgrade soil quality through their deep root system.
- Enhance organic matter through litter fall, root turnover and nutrient cycling from deeper soil layers
- Reduce surface evaporation and weed growth, and improve water use efficiency and add nutrients to the soil when pruned material is applied as mulch at surface.
- Ensure rational utilization of soil moisture stored in deeper soil layers and substrata through tree component.
- Provide fuel, timber and minor forest products (e.g. gum, honey) and thus lessen the farmers' dependence on forest reserves.
- Supplement the diet of poor farm families and ensure their nutritional security.
- Generate much needed cash when aromatic and industrial value plants are grown.
- Support development of soil microbe and earthworm activity.

- Generate employment throughout the year, which substantially increases the income level and cash flow.
- Ensure higher returns to the farmers and bring about cost effectiveness through the economy.
- The Government will focus on quality aspects at all stages of farm operations from sowing to primary processing. The quality of inputs and other support services to farmers will be improved. Quality consciousness amongst farmers and agro processors will be created.

Agroforestry contribution

Agroforestry plays a vital role in the Indian economy by way of tangible and intangible benefits. It has helped in rehabilitation of degraded lands on one hand and has increased farm productivity on the other. At present agroforestry meets almost half of the demand of fuel wood, 2/3 of the small timber, 70-80 per cent wood for plywood, 60 per cent raw material for paper pulp and 9-11 per cent of the green fodder requirement of livestock, besides meeting the subsistence needs of households for food, fruit, fibre, medicine etc. Agroforestry is also playing the greatest role in maintaining the resource base and increasing overall productivity in the rainfed areas in general and the arid and semi-arid regions in particular. Industries have taken uppoplar, *Eucalyptus,* bamboos, *Acacia, Casuarina,Ailanthus* and teak for commercial agroforestry due to their great market potential. Genetically improved clonal planting stock of eucalypts, poplars and acacias has transformed the productivity and profitability of plantations. Average yields from such clonal plantations are 20 to 25 times higher compared to the average productivity of forests in India. Almost 50 million plants of improved Eucalyptus are being planted every year (Dhyani et al., 2013). In fact, agroforestry has high potential for simultaneously satisfying three important objectives viz., protecting and stabilizing the ecosystems; producing a high level of output of economic goods; and improving income and basic materials to rural population. Besides, agroforestry is capable of conserving natural resources under different agro-climatic regions and is the only option to increase the forest/tree cover from present less than 25% to 33% in the country.

Constraints in promotion of Agroforestry

During last more thanthree decades many agroforestry technologies have been developed and demonstrated by various research organizations. But most of them have not reached to farmer's field for want of awareness, inadequate infrastructure and lack of policy support. Therefore, the desired impact has not been observed in terms of adoption of technology. The major reason for this is that agroforestry sector is disadvantaged by adverse policies, legal constraints and lack of coordination between the government sectors to which it contributes viz. agriculture, forestry, rural development, environment and trade. Absence of appropriate policy and institutional arrangement to provide farmers with clear incentives to plant and protect trees that contribute to both ecosystem function and rural livelihoods is a great hurdle. Existing rules and regulations are greatest obstacles in felling, transport and marketing of agroforestry products and they vary from state to state. Agroforestry has to be declared at par with agriculture in availing credit and other subsidies by poor farmers (Dhyani et al., 2013). The agroforestry technologies have been successful in the areas where farmer's got incentive in terms of quality planting material and assured market for example in case of *Poplar, Leucaena* and *Eucalyptus*. Availability of quality planting material of trees is one of the major concerns and need to be addressed urgently.

Agroforestry and Ecosystem Services

Agroforestry has the potential to provide most or all the ecosystem services. The Millennium Ecosystem Assessment has categorized the ecosystem services into provisioning service (e.g., fuel-wood, fodder, timber, poles etc.), regulating service (hydrological benefits, micro-climatic modifications), supporting service (nutrient cycling, agro-biodiversity conservation), and cultural service (recreation, aesthetics). Agroforestry is playing the greatest role in maintaining the resource base and increasing overall productivity in the rainfed areas in general and the arid and semi-arid regions in particular. Agroforestry land use increases livelihood security and reduces vulnerability to climate and environmental change. There are ample evidences to show that the overall (biomass) productivity, soil fertility improvement, soil conservation, nutrient cycling, microclimate improvement, and carbon sequestration potential of an agroforestry system is generally greater than that of an annual system. Agroforestry has an important role in reducing vulnerability, increasing resilience of farming systems and buffering households against climate related risks. It also provides for ecosystem services - water, soil health and biodiversity. Some of the contributions of agroforestry for the ecosystem services are presented here.

Agroforestry for food and nutritional security

The country's food production has increased many folds since independence but recent improvements in food supply have been insufficient to fulfill the nutritional needs of the common person in an ever increasing population of the country. Agroforestry with appropriate tree- crop/ legume combination is one option in this regard. The different agroforestry systems provide the desired diversification options to increase the food security and act as an insurance against the low production during drought and other stress conditions. Agroforestry also provides nutritional security because of diverse production systems which include fruit, vegetables, legumes, and oilseed crops, medicinal and aromatic plants in addition to normal food crops grown by the farmers. With the rapid growth of urbanization and economic growth in the country, farming community have witnessed unprecedented opportunities for moving beyond subsistence farming to supplying products needed by urban population. Agroforestry products such as timber, fruit, food, fibre, fodder, medicine and others are progressively meeting the subsistence needs of households and providing the platform for greater and sustained productivity. Thus, aroforestry systems offer opportunities to farmers for diversifying their income and to increase farm production. Research results from different agro climatic regions of the country show that financial returns generated from agroforestry systems vary greatly but are generally much higher than returns from continuous unfertilized food crops. The higher returns associated with agroforestry can translate into improved household nutrition and health, particularly when women control the income.

Agroforestry has proven as an important tool for crop diversification. By virtue of diversity of the components of the agroforestry systems like fruits, vegetables, nutritional security to the communities could be ensured. In agroforestry, the potentially higher productivity could be due to the capture of more growth resources e.g. light or water or due to improved soil fertility. The best example is of poplar (*Populus deltoides*) - a popular species in agroforestry system in the Upper Indo-gengetic region. Poplar was a best choice as it was fast growing, compatible with wheat and other crops and has industrial use. Therefore, poplar (*Populus* spp.) based agroforestry in northern India made rapid strides. Woodlots of other fast growing trees such as *Eucalyptus* spp., *Leucaena leucocephala*, *Casuarina equisetifolia*, *Acacia mangium*, *A. auriculiformis, Ailanthus*, teak and *Melia dubia* are also becoming increasingly popular among the farmers in several parts of the country due to their great market potential. If agroforestry is promoted properly, it can contribute substantially for commodities such as timber (85%), biofuel (80%) and fuelwood (49%) and to some extent for fruits (15.63%), fodder (10%) and food grains (9%) in the long run (Dhyani et al., 2013).

Agroforestry for fodder production

Trees and shrubs often contribute substantial amount of leaf fodder in arid, semi-arid and hill regions during lean period through lopping/pruning of trees, popularly known as top feed. The leaf fodder yield depends on species, initial age, lopping intensity and interval as well as agro climatic conditions. Silvipastoral system is the most appropriate land use system for degraded lands. The top feeds are also considered very important in vegetation stabilization and sustained productivity of rangelands (Dhyani, 2003). They also play an important role as windbreaks and by providing shade for the grazing animal. The important ones are *Prosopis cineraria*, *Albizzia lebbeck*. *Acacia* spp., *Leucaena leucocephala*, *Dalbergia sissoo*, *Ailanthus excelsa*, *Azadirachta indica*,*Acacia leucophoela etc.* for the arid and semi –arid region and *Grewia optiva, Morus alba*, *Celtis australis*, *Albizia*, Oaks, Ficus etc. for the hilly regions. Bamikole *et al*., (2003) reported that feed intake, weight gain, digestibility and nutrient utilization can be enhanced by feeding *Ficus religiosa* in mixture with *Panicum maximum*, and it can be used in diet mixtures up to 75% of Dry Matter fed. Dagar *et al*. (2001) reported that for silvipastoral system on alkali soils *Prosopis juliflora*, *Acacia nilotica* and *Tamarix articulata* are the most promising trees and *Leptochloa fusca*, *Chloris gayana* and *Brachiaria mutica* most suitable grasses. *L. fusca* in association with *P. juliflora* produced 46.5 t ha^{-1} green fodder over a period of four years without applying any amendments and fertilizer.

Agroforestry for energy security and biofuel production

A large part of India’s population mostly in rural areas, does not have access to the conventional source of energy even today. The main biomass energy sources in rural areas include wood (from forest, croplands and homesteads), cow dung and crop biomass. Among the sources 70-80% energy comes through biomass from trees and shrubs. Due to the agroforestry initiatives large amount of woods are now being produced from outside the conventional forestlands. Small landholdings and marginal farmers, through short rotation forestry and agroforestry practices are now providing the bulk of country’s domestically produced timber products. Ravindranathan *et al*. (1997) reported for a Karnataka village that 79 per cent of all the energy used came mainly from trees and shrubs. *Prosopis juliflora* due to high calorific value of over 5000 Kcal is the major source of fuel for the boilers of the power generation plants in Andhra Pradesh. About Rs.700-1300/t is the price offered for *P. juliflora* wood at factory gate depending on the season and moisture content.An estimated 0.51 million ha area is under *P. juliflora*. R & D can help in enhancing productivity and assisting the power plants in captive plantation management on degraded lands. Promoting bioenergy through *P. juliflora* also encourages tremendous employment generation to the tune of 6.34 million mandays and 7.03 million woman days for fuel making in Tamil Nadu alone.

The fuel wood potential of indigenous (*Acacia nilotica, Azadirachta indica, Casuarina equisetifolia, Dalbergia sissoo, Prosopis cineraria* and *Ziziphus mauritiana*) and exotics (*Acacia auriculiformis, A. tortilis, Eucalyptus camaldulensis* and *E. tereticornis*) trees was studied by Puri *et al.* (1994). The calorific value ranges from 18.7 to 20.8 MJ $kg^{-1}$for indigenous tree species and 17.3 to19.3 MJ kg^{-1} for exotics. Pathak (2002) opined that species such as *C. equisetifolia*, *Prosopis juliflora*, *Leuceana leucocephala* and *Calliandra calothyrsus* have become prominent due to their potential for providing wood energy at the highest efficiency, shorter rotation and also their high adaptability to diverse habitats and climates.

Further the Indian scenario of the increasing gap between demand and domestically produced petroleum is a matter of serious concern. In this connection, fuels of biological origin have drawn a great deal of attention during the last two decades. Biofuels are renewable liquid fuels coming from biological raw materials and has proven to be good substitute for oil in the transportation sector as such biofuels are gaining worldwide acceptance as a solution for problems of environmental degradation, energy security, restricting imports, rural employment and agricultural economy. The potential tree borne oilseeds (TBOs) holding promise for biofuel are *Jatropha curcas*, *Pongamia pinnata*, *Simarouba*, *Azadirachta indica*, *Madhuca* spp., etc.These biofuel species can be grown successfully under different agroforestry systems. There is need to identify the genetically superior germplasm of these biofuel species for higher seed yield and oil content. At present the germplasm of *Jatropha* and *Pongamia* is under multi-location trials to identify the superior germplasm. The promotion of the use of oils could also provide a poverty alleviation option in the rural areas. Farmers can use vacant, waste and marginally used land for growing such trees and benefit from the annual produce, which will add as their income. With the increased green cover the environment will also benefit greatly. The use of oils is also CO_2 neutral, which would mitigate greenhouse effect. But the economics and viability of the Jatropha plantation and bio-fuel production are still at initial stage and will be governed by international market prices of crude oil as well as government policies.

Agroforestry for soil conservation and amelioration

Agroforestry plays a key role in keeping the soil resource productive which is one of the major sustainability issues. Closely spaced trees on slopes reduce soil erosion by water through two main processes: first as a physical barrier of stems, low branches, superficial roots and leaf litter against running water and secondly as sites where water infiltrates faster because of generally better soil structure under trees than on adjacent land.

Agroforestry systems on arable lands envisage growing of trees and woody perennials on terrace risers, terrace edges, field bunds, as intercrops and as alley cropping in the shape of hedge row plantation. Integrating trees on the fields act as natural sump for nutrients from deeper layers of soil, add bio-fertilizer, conserve moisture and enhance productivity of the system. The alley cropping with leguminous trees such as *Leucaena leucocephala* has been most widely used on field bunds for producing mulch material for moisture conservation and nutrient recycling. Alley cropping with *Leucaena leucocephala* was effective for erosion control on sloping lands up to 30%. Reduction in crop yield could be minimized by shifting the management of trees to contour hedge rows. The sediment deposition along the hedge and tree rows increased considerably with consequent reduction in soil loss. Inclusion of trees and woody perennials on farm lands can, in the long run, result in marked improvements in the physical conditions of the soil, e.g. its permeability, water-holding capacity, aggregate stability and soil-temperature regimes. Although these improvements may be slow, their net effect is a better soil medium for plant growth. Experimental evidences give a very clear picture about agroforestry system that increased soil organic carbon and available nutrients than growing sole tree or sole crop. An increase in organic carbon, available N, P and K content in Khejri based silvipastoral system over control, advocating retention/plantation of Khejri tree in pasture land to get higher fodder production and to meet requirement of food, fodder, fuel and small timber is one such example. Similarly, an increase in soil organic carbon status of surface soil under *Acacia nilotica* + *Sacchram munja* and under *Acacia nilotica* + *Eulaliopsis binata* after five years was observed. It was found that *Acacia nilotica* + *Eulaliopsis binata* are conservative but more productive and less competitive with trees and suitable for eco-friendly conservation and rehabilitation of degraded lands of Shiwalik foot hills of subtropical northern India. Rehabilitation of degraded forests is possible through afforestation by adopting integrated land use planning with soil and water conservation measures on watershed basis. NRCAF observed that in agrisilviculture growing of *Albizia procera* with different pruning regimes, the organic carbon of the soil increased by 13-16% from their initial values under different pruning regimes which was five to six times higher than growing of either sole tree or sole crop.

Agroforestry systems have been developed using local resources and conservation-based measures in the North Eastern Hill (NEH) region. Suitable alternate land use systems involving agriculture, horticulture, forestry and agroforestry have been designed with the support of local natural resources for almost identical hydrological behaviour as under the natural system. Under agri-horti-silvipastoral systems, the reduction in runoff was 99% and in soil loss 98%. Combining fine-root system of grasses and legumes, such as *Stylosanthes guyanensis*, *Panicum maximum*, *Setaria* etc. and deep-root system of fodder trees, such as alder (*Alnus nepalensis*) in a silvipastoral system stabilizes terrace risers and provides multiple outputs. In depth evaluation of soil chemical properties of traditional agroforestry system in northeastern region indicated a spectacular increase in soil pH, organic-C, exchangeable Ca, Mg, K, and buildup of avai1able P (Bray's P_2-P) under different agroforestry practices (AFP) within 10-15 years of practice. The exchangeable Al, potential cause of infertility of these lands disappeared completely within 10-15 years of agroforestry practice. The use of trees as shelterbelts in areas that experience high wind or sand movement is well-established example of microclimate improvement that resulted in improved yields. Increased agricultural production due to windbreaks and shelterbelts in India has been well demonstrated. Establishment of micro-shelterbelts in arable lands, by planting tall and fast-growing plant species such as castor bean on the windward side, and shorter crop such as vegetables in the leeward side of tall plants helped to increase the yield of lady's finger by 41% and of cowpea by 21% over the control. In general, the use of shelterbelts brought about a 50% reduction in the magnitude of wind erosion. In studies carried out in an agroforestry system, *Acacia tortilis* (7-yr-old) and guar crop at Jodhpur indicated that relative humidity recorded beneath the tree canopy during the active cropping season of guar was found to be 7% more than in the open. This will, in turn, help for better growth of the crops.

Agroforestry practices have been developed for arable lands and non-arable degraded lands, bouldery riverbed land, torrent control, landslide and landslip stabilization, abandoned mine-spoil area rehabilitation and as an alternative to shifting cultivation. Also, agroforestry systems have proven their efficacy in prevention of droughts, reclamation of waterlogged areas, flood control, rehabilitation of wastelands, ravine reclamation, sea erosion control, control of desertification and mine-spoil rehabilitation and treatment of saline and alkaline lands. Agricultural use of salt affected lands and water resources increases due to increasing demands of food and fodder is yet another example where agroforestry played great role in enhancing the productivity of land and also address the environmental issues. Removal of salts from the soil surface is neither possible nor practical; therefore attempts have been made to minimize adverse effect of salts on crop by developing agro techniques. Central Soil Salinity Research Institute, Karnal (Haryana) has developed developed special planting techniques for sodic and saline soil for better establishment and growth of multipurpose trees. The technique ensures more than 80% tree survival even after ten years in highly alkali soil.

Bio-diversity Conservation through Agroforestry

Agroforestry innovations contribute to bio-diversity conservation through integrated conservation-development approach. Forest degradation has caused immense losses to the bio-diversity, which can be conserved through agroforestry by adopting a strategy of conservation through use. The biodiversity shall help in the development or improvement of new varieties or populations. It will further help in enhancing the availability of improved planting material, which is a key to the increase the productivity and production at farm level. Swaminathan (1983) has pointed out that biodiversity is the feed stock for a climate resilient agriculture. Agroforestry with components like trees, agricultural crops, grasses, livestock, etc. provides all kinds of life support system. Trees in agro ecosystems in Rajasthan and Uttarakhand have been found to support threatened cavity nesting birds and offer forage and habitat to many species of birds. Traditional agroforestry systems are excellent examples of agro-biodiversity conservation. The best examples are the tropical homegardens of Western Ghats (India) and north-eastern hill region. Nonetheless, agroforestry may not avert all species losses. With divergent life forms such as trees, agricultural crops, grasses, livestock, etc., it may act as an effective buffer to prevent such losses, especially in the smallholder land use systems where there are a variety of species than in the larger ones.

Carbon Sequestration potential of Agroforestry

Agroforestry has importance as a carbon sequestration strategy because of C storage potential in its multiple plant species and soil as well as its applicability in agricultural lands and in reforestation. Agroforestry can also have an indirect benefit on C sequestration when it helps to decrease pressure on natural forests, which are the largest sinks of terrestrial C. Another indirect avenue of C sequestration is through the use of agroforestry technologies for soil conservation, which could enhance C storage in trees and soils. The analysis of Carbon stocks from various parts of the world showed that significant quantities could be removed from the atmosphere over the next 50 years if agroforestry systems are implemented on a global scale. For increasing the C sequestration potential of agroforestry systems practices such as- Conservation of biomass and soil carbon in existing sinks; Improved lopping and harvesting practices; Improved efficiency of wood processing; fire protection and more effective use of burning in both forest and agricultural systems; Increased use of biofuels; increased conversion of wood biomass into durable wood products needs to be exploited to their maximum potential. Agroforestry thus contributes to the resilience of agriculture by adaptation and mitigation of climate change effects. In India, evidence is now emerging that agroforestry systems are promising land use system to increase and conserve aboveground and soil carbon stocks to mitigate climate change (Dhyani *et al*., 2009b). Average sequestration potential in agroforestry in India has been estimated to be 25 t C ha^{-1} over 96 million ha. In this way the total potential of agroforestry in India to store C is about 2400 million t. In another estimate agroforestry contributes 19.30% of total C stock under different land uses. The potential of agroforestry systems as carbon sink varies depending upon the species composition, age of trees, geographic location, local climatic factors and management regimes. The growing body of literature indicates that agroforestry systems has the potential to sequester large amounts of above and below ground carbon in addition to SOC enhancement, as compared to treeless farming systems.

Agroforestry for Livelihood Security and Employment opportunities

Agroforestry systems due to diverse options and products provide opportunities for employment generation in rural areas. Increased supply of wood in the market has triggered a substantial increase in the number of small-scale industries dealing with wood and wood based products in the near past. Such industries have promoted agroforestry and contributed significantly to increasing area under farm forestry. Recognizing agroforestry as a viable venture, many business corporations, limited companies such as ITC, WIMCO, West Coast Paper Mills Ltd., Hindustan paper Mills Ltd., financial institutes such as IFFCO have entered into the business and initiated agroforestry activities in collaboration with farmers on a large scale. Besides the existing agroforestry practices, there is a tremendous potential for employment generation with improved agroforestry systems to the tune of 943 million person days annually from the 25.4 million ha of agroforestry area.

Sericulture is being practiced in different parts of the country since time immemorial Sericulture with fruit plants and grass model was highly preferred by farmers, followed by sericulture with field (uplands) crops. Now, tasar sericulture is being promoted in different districts of Bundelkhand region. For this, tasar sericulture insect *Antheria mylata* is being reared on arjun (*Terminalia Arjuna*) which is common tree species of the forest area in this area. Arjun can also be cultivated under dense plantation (2800 plants per ha at 2 m x 2m spacing) and intensive management for economic tasar cultivation. The plantation is ready for rearing tasar silkworm within 3-4 years. As per the information of Sericulture Directorate, Uttar Pradesh, one ha dense plantation of arjun can generate an income of Rs. 30,000 to 50,000 from tasar cultivation. There is scope of tasar sericulture under agroforestry.

Conclusion

The review of the agroforestry research exhibits its wide spectral potential in sustenance of agriculture as these systems provide food, fodder, fruit, vegetables, fuel wood, timber, medicines, fiber etc. from the same piece of land at a time which not only fulfill the demand of people but also elevate their socioeconomic status and standard of life. Agroforestry is key path to prosperity for millions of farm families, leading to extra income, employment generation, greater food and nutritional security and meeting other basic human needs in a sustainable manner. As mitigation strategy to climate change as well as rehabilitation of degraded land, the conversion of unproductive grasslands and crop land to agroforestry is a major opportunity as it helps for carbon sequestration and makes land productive and reduces further soil degradation.

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Enhancing Rainwater Productivity and Economic Viability of Rainfed Crops through Tank Silt Application

M. Osman[1]

[1]Central Research Institute for Dryland Agriculture, Hyderabad-500 059, Telangana

Email: mdosman@crida.in

ABSTRACT: A study was carried for treated and untreated silt application at four centers namely Nalgonda (Telangana), Warangal, (Telangana) Anantapur (Andhra Pradesh) and Kolar (Karnataka) under farmers participatory action research programme (FPARP) conducted in 2008-09 and 2009-10. The data were collected from these centers and analyzed. The results showed that the contribution of silt application during second year (2009-10) was more pronounced although 2009 was a mega drought year. Rainwater productivity in terms of yields without and with silt application during 2009-10 (2^{nd} year) varied from 0.29 and 0.33 kg/ha/mm in case of mulberry in Kolar to 2.07 and 3.34 kg/ha/mm in groundnut in Anantapur, respectively. Significantly higher yield increase in treated with silt over untreated registered in case of castor (229% or 2.52 q/ha) in Nalgonda and groundnut (153% or 4.07 q/ha) in Anantapur while it was non-significant in case of cotton in Warangal and mulberry in Kolar during 2008-09. Across the crops and between the treated *versus* untreated trials and years, cotton in Warangal district registered the highest benefit-cost ratio in treated (3.75) and untreated (3.14) trials. Water productivity of crops in terms of income accrued per millimeter of water was found to be higher with silt application than without in both the years in all the centers, however, year 2009-10 was better than 2008-09. The additional benefits to cost ratio (BCR) ranged between 5.16 in case of cotton in Warangal and 0.25 in case of mulberry in Kolar. The pay back period (PBP) and BCR at 12% discount rate of silt application in castor cultivation was found to be 6 years and 1.70, respectively while internal rate of return (IRR) worked out to 30%.

Key words: Tank silt, recycling, rainwater productivity and economic viability

In India, higher water productivity and income from rainfed agriculture is constrained by erratic rainfall, low moisture status of soils, poor *in-situ* moisture conservation practices and poor groundwater resources (for supplemental irrigation), besides lack of balanced fertilization and addition of organic matter through different sources. Productivity and profitability from rainfed agriculture can be enhanced along with conservation of natural resources like soil, rainwater and efficient use of nutrients. Under high risk, low productivity and fragile rainfed farming situation, 'water bodies' are found to be the way out after watersheds. Among various water harvesting structures at landscape level, tanks are the most viable, socially acceptable and time tested option to mitigate drought and floods. Of late, their restoration and rejuvenation are being taken through renewed efforts of desilting and recycling like in "Mission Kakatiya" of Telangana State, Sujala-III in Karnataka and National Project for Repair, Renovation and Restoration of Water Bodies (RRR) of Ministry of Water Resources, Government of India. These programs will not only enhance crop yields, mitigate drought and floods but also improve soil health. Tank silt is a rich mine containing all the needed macro and micro nutrients essential for plant growth and also a good source of organic matter.

Droughts and floods are common to rainfed areas and tanks act as drought mitigators and flood moderators. Tanks are eco-friendly and farmers' – friendly. As such, multi-functionality of tanks is well documented (CRIDA, 2006; DHAN, 2004 and Osman *et al*., 2001). The strategy of desilting and its recycling will not only rejuvenate tanks but also improve recharge of groundwater besides improving the soil properties in a cost-effective manner. Small storages like tanks are much more appropriate and effective for groundwater recharge (Mc Cully, 2006) and will also arrest siltation of large reservoirs built at huge cost. The programs for tank management in recent decades have been inadequate in scale, misconceived in design, poor implementation and dubious in their impact (Vaidyanathan, 2001). Thus, there is need of renewed focus on research, new and innovative approaches in development and support services matching with resource allocation and augmentation. There is also possibility of substituting inorganic fertilizers with silt as an organic amendment for improving soil quality, increasing crop productivity, rainwater productivity and economic viability of crop production in rainfed areas. The present study is an attempt in this direction.

Materials and Methods

The study is part of Farmers' Participatory Action Research Program (FPARP) of Ministry of Water Resource, Government of India entitled “Tank Silt as an Organic Amendment for Improving Soil and Water Productivity” implemented by CRIDA in four centers namely, Nalgonda (Telangana) Warangal (Telangana), Anantapur (Andhra Pradesh) and Kolar (Karnataka) during 2008-09 & 2009-10 in collaboration with All India Coordinated Research Project for Dryland Agriculture (AICRPDA) of SAUs and NGOs namely, PEACE (NGO, Nalgonda), MARI (NGO, Warangal), Anantapur (AICRPDA, ORP) and MEOS, NGO) and Kolar (AICRPDA, ORP Bangalore and AME, NGO). The sample farmers (beneficiaries) identified for these centres were 20, 22, 20 and 20, respectively. Castor, cotton, groundnut and mulberry are the dominant crops focused in this study across these four centers as they were the main crops in these centres. “Untreated (without tank silt application) and treated (with tank silt application)” approach was followed for two years for this study. The trials were conducted in farmers’ fields in ‘participatory mode’ and data were collected and analyzed for two cropping seasons. The rate of silt application to farmers' fields was based on textural property of tank sediment and field soil. A user-friendly MS - Excel based tank silt applicator was developed and is available on CRIDA website for deciding number of tractor trolley loads based on either physical or chemical characteristics of tank silt (Figure 1). In this study, tank silt applicator was employed using textural property of both tank sediment and field soil and aimed at improving the clay content of field soil surface (0-15 cm) by 10%. Textural analysis (sand, silt and clay content) of tank sediment and field soil was carried out by employing standard procedure using hydrometer. The number of tractor trolleys varied between 100 to 120 loads per hectare depending on clay content of tank silt, which amounted to 2.5 cm depth of application.

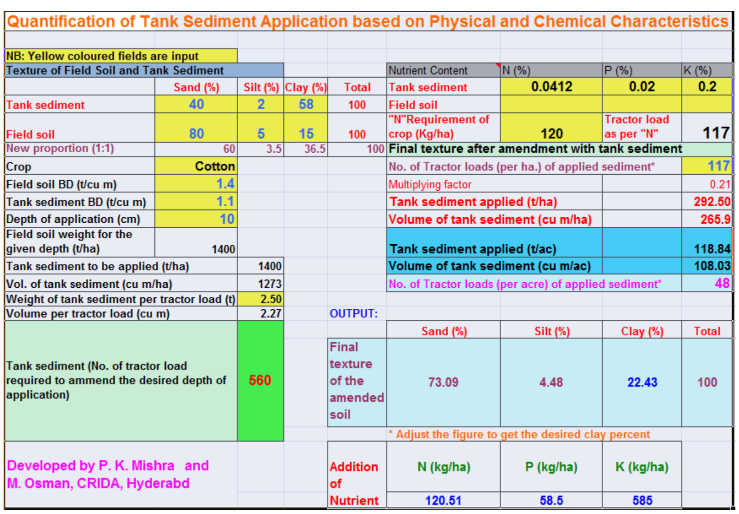

Fig. 1 : Graphic user interface indicating rate of application of tank silt based on textural property of tank silt and field soil and also based on N content of tank silt (www.crida.in/services/tanksilt applicator)

Economic analysis for silt application once in a life time of 25 years using discount factor method

Economic analysis for silt application using discount factor method is exclusively applicable to the low income generating crops like castor, finger millet, etc. ranging from 25 to 30% of the investment made or one time cost incurred on cultivation of the annual arable crops or orchards/tree crops that takes 5 to 6 years to generate income. In this study, an attempt was made for castor crop (I year, as an example) in Nalgonda district. The per ha cost of 100 tractor loads of tank silt incurred for cultivation of castor was worked out to be ₹ 10,000. This is nothing but per ha average additional cost of cultivation of castor incurred only once in a life time of 25 years. However, the improvement in texture of soil is a permanent feature. The average annual additional income accrued per ha of the crop registered ₹ 2570, however, for economic analysis, 5% annual inflation was considered for both the cost and returns using discount factor over a period of 25 years. The methodology adopted by Gittinger (1972) was followed for determining pay back period (PBP), benefit-cost ratio (BCR) and internal rate of return (IRR) without considering intangible benefits of the treatment.

$$\text{PBP} = \sum_{t=1}^{n} \frac{B_n}{(1+i)^n} = \sum_{t=1}^{n} \frac{C_n}{(1+i)^n} \quad \text{---------------} \quad (1)$$

$$\text{BCR} = \sum_{t=1}^{n} \frac{B_n}{(1+i)^n} \Big/ \sum_{t=1}^{n} \frac{C_n}{(1+i)^n} \quad \text{---------------} \quad (2)$$

$$\text{IRR} = \sum_{t=1}^{n} \frac{B_n - C_n}{(1+i)^n} = o \quad \text{---------------------} \quad (3)$$

Where, B_n = present value of benefits accrued in each year (n = 1,2,3……….25)
C_n = present value of costs involved in each year (n = 1,2,3……….25)
n = number of years, i.e 25
i = interest (discount) rate

If the value of BCR is greater than unity, it is considered as economically viable and profitable and *vice versa*. Benefit-cost ratios (BCRs) and incremental/ additional BCRs were worked out for treated and untreated trials to know the economic viability of crops for the two trials and years in the four centers. Student t-test was applied to test the hypothesis of improvement in productivity of crops with recycling of silt. Osman *et al*., (2006) attempted BCRs for treated and untreated treatments with silt in production of cotton and chillies. To arrive at IRR, discounted cash flow (incremental benefit) was worked out for measuring the worth of silt application in the cultivation of castor at which (discount rate) just made the net present value of cash flow to zero.

Results and Discussion

Productivity Enhancement

Across the crops and centres in 2008-09, castor in Nalgonda and groundnut in Anantapur were found to be highly significant while cotton in Warangal and mulberry in Kolar were non-significant. Castor and groundnut registered significantly higher yield increase (229% and 153%) in Nalgonda and Anantapur, respectively while lower yield increase registered in case of cotton (19%) in Warangal and as low as four per cent in case of mulberry crop in Kolar (Table 1). Lower yield increase of mulberry crop is indicative of the fact that silt application had minimal effect on established perennial plant, however, farmers noticed improvement in quality of mulberry leaves and higher intake by silk worms.

Table 1 : Comparative yields of crops without and with silt application during 2008-09 and 2009-10 (q/ha)

District (state)	Crop	2008-09				2009-10			
		Treated with silt	Untreated	P Value **	% increase	Treated with silt	Untreated	P value **	% increase
Nalgonda (Telangana)	Castor*	3.62 ± 0.919	1.10 ± 0.880	0.04	229.1	11.75 ± 0.060	5.25 ± 0.040	0.00	124.0
Warangal (Telangana)	Cotton	21.14 ± 1.075	19.43 ± 1.030	0.26	18.5	25.15 ± 1.068	16.02 ± 0792	0.00	57.0
Anantapur (Andhra Pradesh)	Groundnut	6.88 ± 0.531	2.81 ± 0.248	0.00	152.6	11.69 ± 0.974	7.23 ± 0.700	0.00	61.7
Kolar (Karnataka)	Mulberry	28.8 ± 3.13	27.5 ± 3.17	0.78	4.3	11.2 ± 1.07	9.9 ± 0.90	0.37	13.1

* indicates substitution of castor with cotton during second year in the same plot

** Probability corresponding to t-test

During 2009-10, the effect of (silt) technology was more pronounced, although 2009 was a mega drought year. As such, cotton in Warangal and Nalgonda and groundnut in Anantapur were found to be highly significant while mulberry in Kolar registered non-significant. Evidently, highly significant yield increase registered 124% in case of cotton which was replaced on castor in the same plot in the second year in Nalgonda followed by groundnut (about 62%) in Anantapur and cotton (57%) in Warangal (Table 1). Thus, it is inferred that silt application not only improved yield but also, motivated farmers to diversify to other crops for realizing higher economic benefits.

Rainwater Productivity

Efficient utilization in terms of yield(s) per millimeter of rainwater (kg/ha) use was noticed in treated trials in the second year (2009-10) than the first year (2008-09) in all the crops except mulberry in Kolar (Table 2(a)). The response was high even in severe drought year (2009) indicating higher impact of silt application in realizing higher rainwater use in Nalgonda, Warangal and Anantapur districts. The impact of silt application on mulberry was not high as it was an established perennial plant. Higher water use efficiency registered in case of cotton in place of castor, cotton and groundnut in Nalgonda, Warangal and Anantapur districts were attributed mainly to the better soil mixing (aggregation) in the second year, respectively.

Table 2(a) : Rainwater use in different crops w.r.t yield

District	Crop	Rainwater use (kg/ha/mm)			
		2008-09 (year I)		2009-10 (year II)	
		With silt	Without silt	With silt	Without silt
Nalgonda	Castor*	0.48	0.14	3.89	1.74
Warangal	Cotton	2.57	2.17	3.35	2.00
Anantapur	Groundnut	1.86	0.74	3.34	2.07
Kolar	Mulberry	0.52	0.50	0.33	0.29

* The farmers preferred cotton in the same plot during second year

The yields without and with silt application during 2008-09 (I year) varied from 0.14 and 0.48 kg/ha/mm in case of castor in Nalgonda to 2.17 and 2.57 kg/ha/mm in case of cotton in Warangal, respectively. While the yields with silt application during 2009-10 (2nd year) ranged between 0.33 kg/ha/mm in case of mulberry in Kolar and 3.89 kg/ha/mm in case of cotton (the farmers preferred cotton to castor in the same plot in 2nd year) in Nalgonda but, the yields without silt application varied from as low as 0.29 kg/ha/mm in case of mulberry in Kolar to 2.07 kg/ha/mm in case of groundnut in Anantapur. The lower yield of castor in 2008-09 was due to the highly erratic and uneven distribution of rainfall i.e., rainfall started late in mid July and ended in September in 2008. Thus, the application of silt has resulted in resilience to moisture stress in terms of more or less normal crops yield.

Income per unit of water (₹/ha/mm)

Table 2(b) shows higher rainwater use in terms of income per millimeter of water in the second year than in the first year. As expected, the rainwater use was higher with silt application than without silt in all the crops in the four selected districts in both the years. The income accrued with silt application in the second year varied from 63.3 (₹/ha/mm) in case of mulberry in Kolar to 116.7 (₹/ha/mm) in cotton in Nalgonda. Similarly, the income accrued without silt application in the II year ranged between 47.0 and 60.0 ₹/ha/mm in case of groundnut and cotton in Anantapur and Warangal, respectively (Table 2(b)). The reasons attributed for these variations is similar as cited in the case of yield per millimeter of water.

Table 2(b): Water productivity in terms of ₹/ha/mm

(Constant at 2008)

District	Crop	Water productivity (₹/ha/mm)			
		2008-09 (year I)		2009-10 (year II)	
		With silt	Without silt	With silt	Without silt
Nalgonda	Castor*	10.9	3.3	116.7	52.2
Warangal	Cotton	72.6	61.3	100.5	60.0
Anantapur	Groundnut	46.0	14.8	84.5	47.0
Kolar	Mulberry	83.7	80.5	63.3	54.1

*indicates substitution of castor with cotton during second year in the same plot

While in first year, the higher income accrued with silt application ranged between 10.9 (₹./ha/mm) in castor in Nalgonda and 83.7 (₹/ha/mm) in mulberry in Kolar. However, the income derived without silt application varied from 3.3 (₹./ha/mm) in case of castor in Nalgonda to 80.5 (₹./ha/mm) in mulberry in Kolar. Thus, it is evident from the above that water productivity in terms of yield and income accrued per millimeter of water was found to be higher with silt application than without silt application indicating the positive impact of silt application irrespective of erratic behaviour of monsoon.

Economics of crops

Across the crops cultivated in the four districts in 2008-09 (I year), the per ha cost of cultivation involved in treated trials ranged between ₹ 29403 in case of cotton in Warangal and ₹ 14929 in case of castor in Nalgonda while the returns accrued varied from ₹ 60276 to ₹ 8211 in Warangal and Nalgonda districts, respectively. As such, BCR ranged between 2.05 and 0.55 for cotton and castor in Warangal and Nalgonda, respectively (Table 3(a)).

Table 3(a) : Economics of crops with and without silt application for different centers, 2008-09

(Constant at 2008)

District	Crop	With (treated)			Without (untreated)		
		Total cost of cultivation (₹/ha)	Gross returns (₹/ha)	BCR	Total cost of cultivation (₹/ha)	Gross returns (₹/ha)	BCR
Nalgonda	Castor*	14929	8211	0.55	11175	5641	0.50
Warangal	Cotton	29403	60276	2.05	23287	55423	2.38
Anantapur	Groundnut	15850	20288	1.28	8025	6741	0.84
Kolar	Mulberry	25932	43311	1.67	13728	41603	3.03

*indicates substitution of castor with cotton during second year in the same plot

In untreated trials, the per ha cost of cultivation incurred varied from ₹ 23287 in case of cotton in Warangal to ₹ 8025 in case of groundnut in Anantapur while the returns accrued ranged between ₹ 55423 in case of cotton in Warangal and ₹ 5641 in case of castor in Nalgonda district. The BCRs varied from 3.03 in case of mulberry in Kolar to 0.50 in case of castor in Nalgonda district in 2008-09. In 2009-10, as expected the per ha costs and returns of crops registered higher in treated trials than untreated in each of the four districts (Table 3(b)).

Table 3(b) : Economics of crops with and without silt application for different centers, 2009-10

(Constant at 2008)

District	Crop	With (treated)			Without (untreated)		
		Total cost of cultivation (₹/ha)	Gross returns (₹/ha)	BCR	Total cost of cultivation (₹/ha)	Gross returns (₹/ha)	BCR
Nalgonda	Castor*	12189	30230	2.48	8435	12820	1.52
Warangal	Cotton	20280	76050	3.75	14164	44475	3.14
Anantapur	Groundnut	18085	29660	1.64	10537	15595	1.48
Kolar	Mulberry	18086	21520	1.19	5882	18470	3.14

*indicates substitution of castor with cotton during second year in the same plot

It may be seen that in treated trials, the per ha cost of cultivation involved ranged between ₹ 20280 in case of cotton in Warangal and ₹ 12189 in case of cotton in Nalgonda (the farmers preferred cotton to castor in the same plot in the second year) while returns accrued varied from ₹ 76050 in case of cotton in Warangal to ₹ 21520 in case of mulberry in Kolar. BCR ranged between 3.75 and 1.19 in Warangal and Kolar, respectively. In untreated plots, the BCR ranged between 3.14 and 1.48 in case of cotton and groundnut in Kolar and Anantapur, respectively.

Economics of technology (impact of silt application)

Economics of silt application as a potential technology for crop improvement was analyzed at two levels. Firstly using the figures of yield and income at current prices. Then the data were analyzed in the investment analysis mode. For the first approach, the incremental costs and returns analysis was used, while for the investment analysis, discounting factor method was employed.

Impact of silt application reveals that the additional returns accrued per ha due to silt application registered higher in the second year (2009-10) compared to the first year (2008-09) in all the crops across the four districts. While marginal difference in additional cost incurred (cost of silt application) was found in Anantapur between the two years but, no difference in additional cost was noticed in Nalgonda, Warangal and Kolar. Evidently, higher additional BCRs registered in the second year than in the first year (Table 4). In the second year among the different crops grown in the four districts, additional BCRs were found to be higher in cotton (5.16) in Warangal indicating that for every one rupee per ha of additional investment made on production of cotton resulted to accrue additional gross returns of over ₹ 5.00 followed by cotton (4.46) in Nalgonda, groundnut (1.86) in Anantapur and as low as 0.25 in case of mulberry in Kolar indicating that the silt application was of no use for already established plants in moderately good soils.

Table 4 : Economics of technology (impact of silt application)

District /State	**Crop**	**I-year**			**II-year**		
		Additional cost (₹/ha)	**Additional returns (₹/ha)**	**BCR**	**Additional cost (₹/ha)**	**Additional returns (₹/ha)**	**BCR**
Nalgonda (AP)	Castor*	3754	2570	0.68	3754	17410	4.64
Warangal (T)	Cotton	6116	4853	0.79	6116	31575	5.16
Anantapur (AP)	Groundnut	7825	13541	1.73	7548	14065	1.86
Kolar (K)	Mulberry	12204	1708	0.14	12204	3050	0.25

*indicates substitution of castor with cotton during second year in the same plot

AP = Andhra Pradesh T = Telangana   K = Karnataka

In the first year, the higher additional BCRs were recorded in case of groundnut (1.73) in Anantapur followed by cotton (0.79) in Warangal, castor (0.68) in Nalgonda while it was lower in mulberry (0.14) in Kolar. Thus, the additional costs and returns analysis gives an extent of profitability and viability of crops for sound agro-climatic regional planning.

Economic analysis for silt application (discount factor method)

It was found that the pay back period was 6 years at which the present value of returns (income) accrued crossed the present value of costs incurred (Table 5). The BCR for silt application in castor growing fields registered 1.70 which was more than unity at 12% discount rate. The present value of benefits accrued was more than the present value of costs incurred implying that the growers of castor crop were recovering the entire amount (@ ₹ 10,000 per ha) spent by the implementing agency in 6 years.

IRR of silt application in cultivation of castor worked out to be higher (30%) indicating that at a discount rate of 30%, the silt application in castor bean cultivation just breaks even, i.e., that growers would earn back the entire investment (@ ₹ 10,000 per ha by implementing agency) and in addition to the amount of 5% annual inflation as operating cost incurred by the farmers in silt application of castor farms and by receiving 30% for the use of money in the meantime. Thus, the study indicates that recycling of tank silt not only will be economically viable but also eco-friendly. Another dimension of tank silt use for agriculture is employment generation and related economic activity in the process besides creation of an additional water storage capacity in tanks. Earlier studies documented the additional benefits like increased soil microbial bio-diversity and improved soil quality (Osman *et al*., 2009).

Conclusion

Silt application technology not only helped the farmers in making their soil rich and get "More Crop and Income Per Drop of Water" but also motivated farmers to diversify to other crops for realizing higher returns. Recycling of silt in rainfed areas not only improves yield and income but also makes use of rainwater efficiently and mitigate dry spells. It is in this backdrop that certain public funded schemes like MGNREGS has included tank desilting as one of the priority works. This common traditional practice that was given up must be revived to benefit not only the cause of natural resources build up but also for enhancing farm productivity and income.

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Table 5 : Economic analysis for silt application in cultivation of castor in Nalgonda, 2008-09

Year	Average cost (₹/ha)	DF 12%	Present worth 12% (₹/ha)	Income (₹/ha)	Present worth 12% (₹/ha)	Incremental benefit (cash flow) (₹/ha)	Present worth 12% (₹/ha)	DF 25%	Present worth (₹/ha)	DF 30%	Present worth (₹/ha)
1	10000	0.893	8930	2570	2295	-7430	-6635	0.800	-5944	0.769	-5714
2	500	0.797	399	2699	2151	2199	1752	0.640	1407	0.592	1302
3	500	0.712	356	2699	1922	2199	1566	0.512	1126	0.455	1001
4	500	0.636	318	2699	1717	2199	1399	0.410	902	0.350	770
5	500	0.567	284	2699	1530	2199	1246	0.328	721	0.269	592
6	500	0.507	254	2699	1368	2199	1115	0.262	576	0.207	455
7	500	0.452	226	2699	1220	2199	994	0.210	462	0.159	350
8	500	0.404	202	2699	1090	2199	888	0.168	369	0.123	270
9	500	0.361	181	2699	974	2199	794	0.134	295	0.094	207

10	500	0.322	161	2699	869	2199	708	0.107	235	0.073	161
11	500	0.287	144	2699	775	2199	631	0.086	189	0.056	123
12	500	0.257	129	2699	694	2199	565	0.069	152	0.043	95
13	500	0.229	115	2699	618	2199	504	0.055	121	0.033	73
14	500	0.205	103	2699	553	2199	451	0.044	97	0.025	55
15	500	0.183	92	2699	494	2199	402	0.035	77	0.020	44
16	500	0.163	82	2699	440	2199	358	0.028	62	0.015	33
17	500	0.146	73	2699	394	2199	321	0.023	51	0.012	26
18	500	0.130	65	2699	351	2199	286	0.018	40	0.009	20
19	500	0.116	58	2699	313	2199	255	0.014	31	0.007	15
20	500	0.104	52	2699	281	2199	229	0.012	26	0.005	11
21	500	0.093	47	2699	251	2199	205	0.009	20	0.004	9
22	500	0.083	42	2699	224	2199	183	0.007	15	0.003	7
23	500	0.074	37	2699	200	2199	163	0.006	13	0.002	4
24	500	0.066	33	2699	178	2199	145	0.005	11	0.002	4
25	500	0.059	30	2699	159	2199	130	0.004	9	0.001	2
	22000	**7.846**	**12413**	**67346**	**21061**	**45346**	**8655**		**1063**		**-85**

Benefit -cost ratio at 12% = $\dfrac{21061}{12413} = 1.70$

Internal rate of return = 25 + 5 $\left(\dfrac{1063}{1063+85}\right) = 30\%$

Pay back period = 6 years

Farmers' perspective on Zero till (ZT) technology demonstration: A case of ZT maize in rice fallows of Andhra Pradesh

G. Nirmala
Principal Scientist (Agrl. Extension)
Central Research Institute for Dryland Agriculture, Santhoshnagar. Hyderabad- 500 059
Email: nirmalatadiparty@gmail.com

Introduction

1. History of zero tillage technology: An ancient practice of India and the World

In general, zero tillage is an ancient practice which involves sowing crop in unprepared soil. This is usually referred to as no till or direct planting or zero till and originated during ancient times of developing countries. The concept has undergone many changes with inclusion of many practices to it in the modern world implying sowing crop in an undisturbed soil left with crop residues. The zero tillage technology facilitates sowing either with surface crop cover or with crop residues leaving less soil disturbance throughout the crop cycle adopting a number of crop rotations termed as conservation agriculture. FAO. 2007, defined conservation agriculture as array of farm management practices that involve minimal disturbance of the soil, retention of residue mulch on the soil surface, and use of crop rotations. In India farmers typically use 'zero till' technology only with second crop after rice in rice fallows usually with rice stubbles in field. The second crop could be wheat as in Indo gangetic plains or pulses in Krishna- Godavari zone.

The reasons stated for adoption of zero tillage were mainly to prevent late sowing of wheat and enhance productivity of wheat. Late sowing of wheat is attributed again to either late maturity or long duration of rice crop. According to Malik *et al.*, 2002, farmers perceive it as technology that saves on time required for land preparation, reduction of *philaris minor*, a weed common in rice fields; and conservation of water resources. Zero tillage throws open challenges of designing appropriate seeding devices for sowing zero till crops in hard crusted rice fallows. Seeding devices ranging from simple broadcast to mechanical seed drills. R&D efforts from agricultural universities, ICAR research institutes and State agricultural department focused mostly on devising seeding devices and chemicals for control of weeds. Many studies have reported that zero-till technology drew good response as a viable resource conservation technology with potentiality to improve resource use pattern and resource use efficiency. In Punjab and Haryana, adoption of zero till wheat technology is most common with rice – wheat cropping systems. According to Meishner, 2001, traditionally farmers go for 6 ploughings with the country plough behind the bullock and over 12 plankings to level the soil which amount to lot of time and labour cost, which can be minimized with zero till technology.

Zero tillage is looked at as one time operation which places seed and fertilizer into an undisturbed soil, while retains adequate surface residues to prevent soil erosion.

Zero tillage has been introduced to achieve different objectives by different organizations. The common benefits reported from zero tillage were early planting, prevention of soil degradation, maintains more crop residues, improves soil conditions, reduction of cost of cultivation, less maintenance costs, satisfaction of protection of environment and labour saving, reduction of diesel consumption by 50-70% and proportional reductions of green house gas emissions (Singh *et al*, 2007); immobilizing carbon in soil organic matter and surface residues more than conventional tillage method (Desperch, 1998).

Table -1 Area under ZT by continent

Continent	Area (hectares)	% of Total
South America	49,579,000	46.8
North America	40,074,000	37.8
Australia and New Zealand	12,162,000	11.5

Asia	2,530,000	2.3
Europe	1,150,000	1.1
Africa	3,68,000	0.3
Total	**105,863,000**	**100**

In almost every country some activity of ZT is found in some form either in research or in the field. A brief history of ZT in many countries which throws light on ZT utility and its resource conservation efficiency conservation gives us information on how the concept has taken different forms. is described here.

Zero tillage or Reduced tillage?

In Krishna- Godavari zone and Indo- Gangetic plains of India, ZT technology commonly mentioned as sowing under rice fallows without much opening up of the soil in first standing crop nearing harvest. This is contrary to the belief that ZT is a permanent operation to as it means that in many countries like Argentina which has largest area under zero till mentions as permanent no till and occasional practicing is not zero tillage as usually in some areas such as in India.

2. Farmers perceptions on ZT:

Maize crop has been cultivated in Andhra Pradesh since 1999. Since then acreage over a decade period from 1999 to 2009 had increased from 3.60 lakh acres to 5.30 lakh acres in *kharif*, 0.92 lakh acres to 3.58 lakh acres in *Rabi*. The productivity of the crop varied between 2205 kgs per ha to 4581 kgs per ha depending on the availability of moisture and favorable conditions during *kharif*. In *Rabi crop*, maize crop cultivated under irrigated conditions produced yield ranging between 2996 kgs per ha to 4930 kgs per ha.

Table-2 Area, production and Productivity of Maize in Andhra Pradesh State.

Year	Area (Lakh ha.)			Yield (kg/ha)			Production (lakh MT)		
	Kharif	Rabi	Total	Kharif	Rabi	Annual average	Kharif	Rabi	Total
1999-2000	3.60	0.92	4.52	3030	4149	3258	10.91	3.81	14.72
2000-2001	4.31	0.97	5.28	2572	4876	2996	11.07	4.74	15.81
2001-2002	3.38	0.90	4.28	2921	5187	3401	9.86	4.71	14.57
2002-2003	4.14	1.12	5.26	2205	5123	2827	9.12	5.74	14.86
2003-2004	5.58	1.63	7.21	2996	4946	3437	16.72	8.05	24.77
2004-2005	5.05	1.52	6.57	2451	5446	3142	12.39	8.25	20.64
2005-2006	5.93	1.65	7.58	3538	5998	4073	20.98	9.89	30.87
2006-2007	5.35	1.90	7.25	2398	6189	3391	12.85	11.77	24.62
2007-2008	5.19	2.67	7.86	4581	6590	5263	23.77	17.58	41.35
2008-2009	4.98	3.58	8.56	3148	7409	4930	15.68	26.52	42.20
Normal	5.30	2.26	7.56	3223	6326	4160	17.13	14.80	31.94

Source: www.agrinet.com

Need for improvement of maize productivity: Improving productivity of maize is major criteria in rainfed areas while conserving resources of soil and water. With steady increase in maize area more in AP particularly with *kharif* area than in *rabi*, however, the productivity found to be high in *rabi* season and than in kharif. Rabi maize is cultivated under irrigated conditions and major source of irrigation is groundwater. As there is vast scope of expansion of *rabi* maize area and improve its production with application of zero tillage technology by exploitation of rice fallows through effective utilization of crop residues, soil, and water resources. Demonstration of Zero tillage concept (ZT), mostly popular among rice cultivating farmers' of coastal districts of AP (farmers broadcast black gram seed in rice fallows immediately after rice is harvested), found to be promising technology.

This paper discusses some of the benefits experienced by farmers through zero tillage maize demonstration in Rangareddy district of Andhra Pradesh. The objective of the demonstration is to provide additional benefit of maize crop in rice fallows and improve productivity and income in a sustainable manner; and its adoption as a Good agricultural practice (GAP).

2.1 A case study on zero tillage maize demonstration: farmers' perceptions on various factors of production.

"Is it possible to cultivate a crop without ploughing and opening up of soil?" This was the first reaction of farmers on hearing about the zero till technology. It was clear from this that the whole village was unaware of such technology making demonstration itself very novel in nature. Farmers were skeptical of results till the end of demonstration.

A demonstration was laid out in rice fallows of red soils. Sowing was taken up during first week of December using seed marker possessing pegs at a distance of 30 cms. Women family labour worked on seed marker for placing seed and fertilizers in adjacent holes made by drill. Pre-emergence weedicides were sprayed immediately after sowing, within 48 hours of sowing, to control weeds that might arise from rice stubbles and whole of the field. Other regular management practices such as top dressing, plant protection were similar as in conventionally tilled crop. A field day was conducted to upscale the technology and gather feedback from farmers before the harvest of crop. Farmers perceptions were drawn on different factors such as tillage cost, yields, nett returns, weed management and nutrient and pest management aspects.

Tillage cost: Farmers gained on savings on cost of tillage operations in comparison to conventional practice, as rice fallows possess hard sub surface soil on account of flooding of previous season crop. Minimum of 6 ploughings required to break hard clods amounting to cost escalation to the tune of Rs 6000 per acre in conventional tillage. This was found to have reduced in zero till crop. In this technology the field usually not ploughed and soil is opened up for sowing with seed drill and fertilizer is placed in adjacent hole made with same seed drill. A seed drill specially designed for the purpose actually facilitated in sowing which to a large extent constituted the success factor of technology adoption.

Labour use: Only family labour was utilized throughout all farm operations which incurred low labour cost compared to conventional tillage method. However, the farmer reported high utilization of family labour for continuous monitoring of crop as a night watchman. During night time, particularly at harvesting stage the problem of wild boars have severely inflicted economic damage to crop. In maize crop cultivation, irrespective of ZT or CT method, wild boar causes severe damage particularly after sowing and cob development stages. 60 percent of duration of crop consumed family labour only to guard at nights to prevent from wild boars attack.

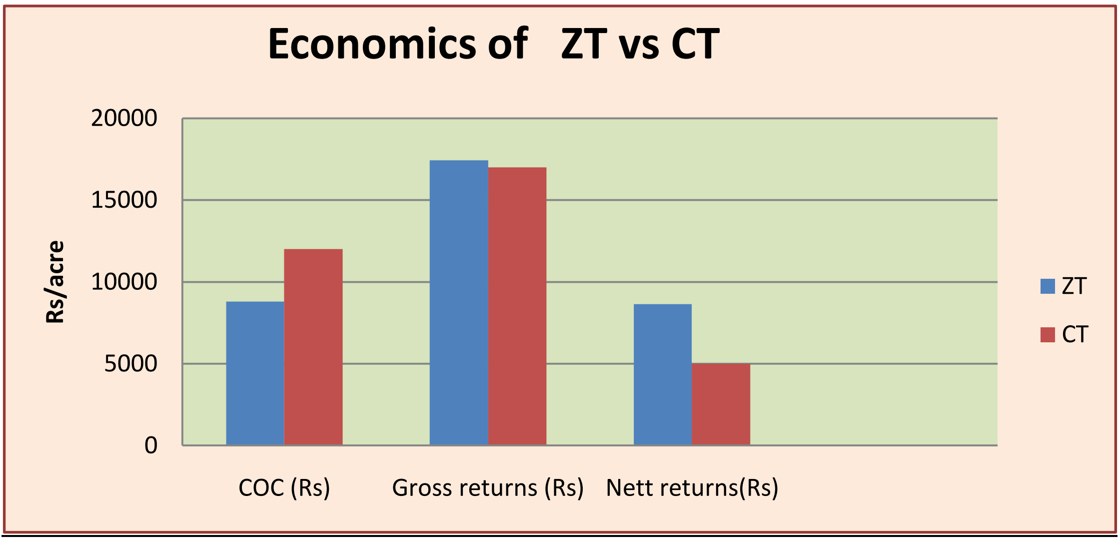
Weed Management: Major thrust in Zero tillage is weed management and its control and as a result weedicides consumed in high proportion. 15 percent of cost of inputs was incurred on weedicides mainly to control weeds and prevent rice stubbles emergence. Zenteir and Campbell (1998) reported, zero tillage found successful only when weedicides prices are low in order to improve weedicide use efficiency. However, inspite of high nett returns from ZT, environment concerns need to be given top priority as chances of contamination of ground water from atrazine sprays that cause severe environmental hazards and as a result and follow-up a well planned integrated weed control measures need to be adopted.

Nutrient management: Many micronutrient deficiencies were identified by farmers during crop growth stage and had to be corrected by series of foliar sprays with N, K and Zn. Corrective measures incurred 35 percent of total cost on inputs. Nitrogen in the form of urea was applied more in ZT crop .This was is in agreement with Grover and Sharma, 2011, who reported higher urea application in zero tilled wheat crop.

In zero tillage technology, fertilizer application is challenging and therefore to derive complete benefit of Zero tillage with Maize crop, a high nutrient feeder, there is need to improve input use efficiency by adoption of soil test based fertilizer application, timely foliar sprays with micronutrients and proper placement of fertilizers.

Nett returns: Zero tillage *rabi* maize accounted 60 percent higher nett returns when compared to Conventional tillage grown in same season. Studies reported variability in Nett returns from high to low depending to cost of inputs and variations in crop yields (Khakbazan and Hamilton, 2012)

Fig- 1 Economics of Zero till vs Conventional tillage of Rabi maize



Yield: Farmers did not find any significant change in yield levels under two technologies of ZT and CT technologies. Yield increase is subjective in nature as farmers with 1-2 quintal gain is not big deal from farmers' point of view. This technology has not demonstrated much yield increase but gains in Nett returns by reduction of tillage cost to the tune of Rs 6000 form attractive proposition to adopt this technology in future.

Fodder security: It has provided 'fodder security' to many livestock holding farmers that supplied adequate dry fodder for animals in summer.

Conclusion

Local factors influence economic performance of zero tillage maize as farmers adopt technologies from profitability point of view in terms of Nett returns and labour use, in contrast to scientist view who look at sustainability of natural resources. However, considering the resource conservation and increasing cost of cultivation Zero tillage has been considered as a promising technology to conserve resources of soil, water and crop residues. In addition to, the benefits derived from saving of tillage time and cost, availability of seed drill for sowing and fertilizer placement are important factors essential for upscaling of zero technology.

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Farmers' Knowledge Perceptions and Adaptation Measures towards Climate Variability

K. Ravi Shankar, R. Nagarjuna Kumar
Central Research Institute for Dryland Agriculture, Hyderabad 500059

Introduction

Indigenous knowledge is generally defined as the "Knowledge of a people of a particular area based on their interactions and experiences within that area, their traditions, and their incorporation of knowledge emanating from elsewhere into their production and economic systems". It is culturally appropriate, holistic and integrative. Incorporating indigenous knowledge is less expensive than bringing in aid for populations unprepared for catastrophes and disasters, or than importing adaptive measures, which are usually introduced in a top- down manner and difficult to implement, particularly because of financial and institutional constraints. Indigenous people that live close to natural resources often observe the activities around them and are the first to identify and adapt to any changes. The appearance of certain birds, mating of certain animals and flowering of certain plants are all important signals of changes in time and seasons that are well understood in traditional knowledge systems. Farmers have been confronted with changing environments for millennia and have developed a wide array of coping strategies, and their traditional knowledge and practices provide an important basis for facing the even greater challenges of climate change. Participatory research and farmer-back-to-farmer models of technology transfer are examples of attempts towards establishing a bridge between traditional knowledge and scientific knowledge. The increasing attention to adaptation to climate change has not come with sufficient emphasis on the local nature of climate adaptation and on the role of local institutions and local governance in shaping adaptation practices (Agrawal *et al*., 2009). Local knowledge is therefore a major priority in the planning of adaptation (Allen, 2006). Indigenous knowledge systems can facilitate understanding and effective communication and increase the rate of dissemination and utilization of climate change mitigation and adaptation options. While the importance of indigenous knowledge has been realized in the design and implementation of sustainable development projects, little attention has been drawn to their incorporation into formal changing climate mitigation and adaptation strategies (Nyong *et al*., 2007).

Climate change is becoming a major driver of disasters, with increasingly frequent and intense floods and storms affecting more people globally. Increased forced displacement is an extremely likely consequence of such events. Heightened drought risk, desertification, sea level rise and changes in the availability of water and fertile land, coupled with reduced access to basic resources, will also fuel longer term migration and forced displacement.

Climate change**: Impacts on Agriculture in India**

Agriculture is one of the largest contributors to India's Gross Domestic Product (GDP), approximately 20%. It is the main source of livelihood for almost 60% of the country's total population. The impacts of changing climate on agriculture will therefore be severely felt in India. It has been projected that under the scenario of a 2.5^0C to 4.9^0C temperature rise in India, rice yields will drop by 32%-40% and wheat yields by 41-52%. This would cause GDP to fall by 1.8%-3.4% (GOI, 2011; Guiteras, 2007; OECD, 2002). Despite the gloomy predictions about the negative impacts for India's agricultural sector, climate change is expected to bring opportunities as well e.g.: production gains through the CO_2 fertilization effect or the expansion of cultivated land to higher altitudes and northern latitudes. However, it must be noted that to date all climate change projections have been accompanied by uncertainty-not primarily concerning trends but extent (IFPRI, 2009; UNFCC, 2009).

Adaptation to Climate change

Agriculture in developing countries is one of the most vulnerable sectors of the global economy to changing climate (Kurukulasuriya *et al.,* 2006; Seo and Mendelsohn 2008c). **Farmers whose livelihoods depend on the use of natural resources are likely to bear the brunt of adverse** changing **climate impacts.** Farmers will be hard hit if they do not adjust at all to new climates (Mendelsohn *et al*., 1994, Rosenzweig and Hillel 1998; Reilly *et al*., 1996). Adaptation to **climate change** requires that farmers first notice that climate has changed, and then identify useful adaptations and implement them (Maddison, 2006). Adaptation is widely recognized as a vital component of any policy response to **climate change**. Studies show that without adaptation, **climate change** is generally detrimental to the agriculture sector; but with adaptation, vulnerability can largely be reduced (Easterling *et al*., 1993; Rosenzweig and Parry 1994; Smith 1996; Mendelsohn 1998; Reilly and Schimmelpfennig 1999; Smit and Skinner, 2002). The degree to which an agricultural system is affected by **climate change** depends on its adaptive capacity. The adaptive capacity of a system describes its ability to modify its characteristics or behavior so as to cope better with changes in external conditions. Adaptive capacity is determined by various factors including recognition of the need to adapt, willingness to undertake adaptation, and the availability of, and ability to deploy, resources (Brown, 2010). Recent empirical studies indicate that farmers have already adapted to the existing climates that they face by choosing crops or livestock or irrigation (Kurukulasuriya and Mendelsohn 2007, 2008; Nhemachena and Hassan 2007; Seo and Mendelsohn 2008a, 2008b) ideal for their current climate. The adaptation strategies must not be used in isolation. For instance, the use of early maturing crop varieties must be accompanied by other crop management practices such as crop rotation or the use of cover crops. This, however, requires additional institutional support, such as credit, access to input and output markets and information.

The objective of the present study was to identify farmers' knowledge perceptions towards climate change along with their farm-level adaptation measures with a view to suggest appropriate research/policy issues which help in facilitating farmers' adaptation to changing climate.

Research Results

A sample of 180 farmers @60 each from Anantapur, Mahbubnagar and East Godavari districts of Andhra Pradesh in South India was selected randomly. Data was collected using a pre-tested interview schedule from the farmers. Percent analysis, correlation and regression, and composite index developed in the study were used for analyzing data.

a) *Farmers' perceptions and Adaptation Measures towards Climate change:*

Table 1. Farmers' Perceptions regarding Climate change in Anantapur

S.No.	Farmers' Perception	Number*	%	Rank
1.	Rise in temperatures	57	95	I
2.	Decrease in rainfall	56	93	II
3.	Advanced onset of monsoon	54	90	III
4.	Middle, long dry spells	53	88	IV
5.	Terminal heavy rains	50	83	V
6.	Uneven distribution of rainfall thereby, affecting length of growing season	49	82	VI
7.	Prevalence of pests and diseases	47	78	VII
8.	ITKs for weather forecast failing	41	68	VIII

*Multiple responses

Table 2. Farmers' Adaptation Measures towards Climate change in Anantapur

S.No.	Farmers' Adaptation Measures	Number*	%	Rank
1.	Buy insurance	56	93	I
2.	Change in planting dates of groundnut (go or early sowings may be between May end to early June)	55	92	II

3.	Intercrop with red gram in 8:1 or 12:1 ratio.	48	80	III
4.	Intercrop with castor contemplated	47	78	IV
5.	Construct water harvesting structures under MGNREGA	45	75	V
6.	Require quick maturing, drought resistant varieties	42	70	VI

From table 1, it is clear that rise in temperatures followed by decrease in rainfall, advanced onset of monsoon, middle long dry spells, terminal heavy rains, prevalence of pests and diseases and ITKs for weather forecast failing are the major farmers' perceptions in that order of magnitude regarding **climate change** in Anantapur. Bryan et al. (2009) in their study in Ethiopia and South Africa reported that farmers experienced increased temperature and decreased rainfall. Similar observations were reported by Vedwan and Rhoades (2001), Hageback et al. (2005), Maddison (2006), Gbetibouo (2009) and Dejene (2011) in their studies. Results of a study conducted in Bundi district of Rajasthan, India revealed farmers' perceptions to **climate change** as increase in temperatures, decreased rainfall and long dry spells. The chief adaptation measures followed by farmers' are change in planting time, intercropping, soil and water conservation and planting drought tolerant crops (Dhaka *et al*., 2010).

It is clear from table 2, that buying insurance, changing planting dates of groundnut, intercrop with red gram, construct water harvesting structures, and require quick maturing, drought resistant varieties in that order of magnitude are the major adaptation measures followed by farmers' towards **climate change** in Anantapur. This finding is consistent with that of Swanson *et al*., (2008) who reported that crop insurance was widely used by farmers in Foremost and Coaldale regions of Canada and the common feeling was that even though it might not provide sufficient returns for losses incurred it does offer some protection. It has allowed them to continue farming. Agricultural insurance can help people to cope with the financial losses incurred as a result of weather extremes. Insurance supports farmers in their adaptation process and prevents them from falling into absolute poverty. Apart from stabilizing household incomes by reducing the economic risk, insurance can also enhance farmers' willingness to adapt, to make use of innovations and invest in new technologies (Ilona *et al*., 2011). Agricultural adaptation involves two types of modifications in production systems. The first is increased diversification that involves engaging in production activities that are drought tolerant and or resistant to temperature stresses as well as activities that make efficient use and take full advantage of the prevailing water and temperature conditions, among other factors. Crop diversification can serve as insurance against rainfall variability as different crops are affected differently by climate events (Orindi and Eriksen 2005; Adger *et al*., 2003). The second strategy focuses on crop management practices geared towards ensuring that critical crop growth stages do not coincide with very harsh climatic conditions such as mid-season droughts. Crop management practices that can be used include modifying the length of the growing period and changing planting and harvesting dates (Orindi and Eriksen, 2005).

Table 3. Farmers' Perceptions regarding Climate change in Mahbubnagar

S.No.	Farmers' Perception	Number*	%	Rank
1.	Rise in temperatures	55	92	I
2.	Decrease in rainfall	53	88	II
3.	Advanced (some places timely) onset of monsoon	51	85	III
4.	Middle long dry spells accompanied by cloudy weather during flowering	48	80	IV
5.	Terminal heavy rains	46	77	V
6.	Prevalence of pests and diseases (powdery mildew, mold in castor; smut and jassids in paddy)	41	68	VI

From table 3, it is clear that rise in temperatures followed by decrease in rainfall, prolonged dry spells in between rains, terminal heavy rains and prevalence of pests and diseases (powdery mildew, mold in castor; smut and jassids in paddy) are the major farmers' perceptions in that order of magnitude regarding **climate change** in Mahbubnagar. It is striking that farmers across the world show a remarkable unanimity in observations of seasonal change, particularly regarding rain falling in most intense bursts; and generally higher temperatures and longer hot, dry spells within rainy seasons, with effects on soil moisture (Jennings and

Magrath, 2009). Kemausuor *et al*., (2011) reported that a large percentage (93%) of farmers was of the opinion that the timing of the rains is now irregular and unpredictable.

Table 4. Farmers' Adaptation Measures towards Climate change in Mahbubnagar

S.No.	Farmers' Adaptation Measures	Number*	%	Rank
1.	Staggered sowings (dry paddy, castor, red gram and cotton in kharif), (groundnut, paddy, chillies and tobacco in rabi)	50	83	I
2.	Change in Planting dates and planting different crops	49	82	II
3.	Require drought resistant varieties	45	75	III
4.	Water harvesting structures started under MGNREGA	41	68	IV

It is clear from table 4, that staggered sowings, change in planting dates, require drought resistant crops, and construct water harvesting structures are the major adaptation measures followed by farmers' towards changing climate in Mahbubnagar.

Also, the farmers' in Mahbubnagar are accustomed to observe the rainy season and if the season is favourable with good rains, they will continue farming. Otherwise, they migrate and work as construction labour at Gangavati, Hyderabad and Bangalore. Higher temperatures, pest and disease attack on crops were the chief perceptions of farmers towards climate change, while, planting different crops and water conservation were the main adaptation strategies of farmers in Ogbomosho agricultural zone of Oyo state in Nigeria. (Ayanwuyi *et al*., 2010).

Table 5. Farmers' Perceptions regarding Climate change **in East Godavari**

S.No.	Farmers' Perception	Number*	%	Rank
1.	Rise in temperatures.	54	90	I
2.	Decrease in rainfall.	53	88	II
3.	Pest and disease incidence is high for kharif paddy like BPH, BLB and stem borer (at transplanting stage).	51	85	III
4.	Terminal heavy and unseasonal rains.	49	82	IV
5.	ITKs for rain forecasts are failing.	45	75	V

From table 5, it is clear that rise in temperatures, followed by decrease in rainfall, incidence of pests and diseases, terminal heavy cyclonic rains, and ITKs for rain forecasts failing are the major farmers' perceptions in that order of magnitude regarding **climate change** in East Godavari.

Table 6. Farmers' Adaptation Measures towards Cimate change in East Godavari

S.No.	Farmers' Adaptation Measures	Number*	%	Rank
1.	Go for early (June) sowings to avoid November cyclones coinciding with harvests.	56	93	I
2.	Salt water spray for harvested paddy stalks to avoid discoloration and regermination. For paddy in field, tying with rope and sticks on four sides to keep them erect and not falling down.	55	92	II
3.	Strengthening of river banks and improved drainage.	53	88	III
4.	Survey number wise insurance covering low lands.	50	83	IV
5.	Loans to tenant farmers though introduced, falls short of actual requirements in terms of coverage.	48	80	V

It is clear from table 6, that early sowings, salt water spray for harvested paddy stalks, strengthening of river banks and improved drainage, survey number wise insurance, and loans to tenant farmers are the major adaptation measures perceived by farmers' towards **climate change** in East Godavari. Migrate as construction labour if monsoon fails, particularly in rainfed areas of the district is another common phenomenon (Ravi Shankar *et al*., 2013). Improving the adaptive capacity of disadvantaged communities requires ensuring access to resources, income generation activities, greater equity between genders and social groups, and an increase in the capacity of the poor to participate in local politics and actions (IISD 2006). Thus, furthering adaptive capacity is in line with general sustainable development and policies that help reduce pressure on resources reduce environmental risks, and increase the welfare of the poorest members of the society.

Since most smallholder farmers are operating under resource limitations, lack of credit facilities and other inputs compound the limitations of resource availability and the implications are that farmers fail to meet transaction costs necessary to acquire the adaptation measures they might want to and at times farmers cannot make beneficial use of the available information they might have (Kandlinkar and Risbey 2000). Lack of access to credit has been observed in previous studies (Nhemachena and Hassan, 2007) to be a barrier to responding to climate change. A better understanding of how farmers' perceive changing climate, ongoing adaptation measures, and the factors influencing the decision to adapt farming practices is needed to craft policies and programmes aimed at promoting successful adaptation of the agricultural sector (Bryan *et al*., 2009).

- The mean adaptation index value for floods (12.13) (East Godavari) is greater than that for droughts (11.90, 11.65) (Anantapur and Mahbubnagar respectively).
- Practices like construct water harvesting structures, plant drought resistant crops, crop management by adjusting planting dates and soil management by mulching, conservation tillage showed highest adaptation in Anantapur and Mahbubnagar. This amply illustrates the need for water harvesting, storage and reuse.
- Practices like flood forecasting and early warning systems, drainage aspects, better soil and crop management and community based water management showed highest adaptation in East Godavari. The problem here is managing excess water.
- Education, farming experience, and farm size were contributing significantly at 0.01 level with farmers' adaptation to climate change.
- Extension's role is in providing knowledge related to adaptation to changing climate and communication, so that farmers' can make informed decisions.

Conclusion

Capacity building at local, national and regional levels is vital to enable developing countries like India to adapt to changing climate. Capacity building, for example to integrate changing climate and socio-economic assessments into vulnerability and adaptation assessments, helps to better identify effective adaptation options and their associated costs. Education and training of stakeholders, including policy-level decision makers, are important catalysts for the success of assessing vulnerabilities and planning adaptation activities, as well as implementing adaptation plans. The different policy options include raising awareness about changing climate and the appropriate adaptation methods, facilitating the availability of credit, investing in yield increasing technology packages to increase farm income, creating opportunities for off-farm employment, conducting research on use of new crop varieties and livestock species that are better suited to drier conditions, encouraging informal social networks, and investing in irrigation. Extension can make a significant contribution through enhanced farmer decision making in the light of changing climate. The most important purpose for extension today is to bring about the empowerment of farmers, so that their voices can be heard and they can play a major role in deciding how they will mitigate and adapt to changing climate.

As national and international policy makers turn their attention to changing climate adaptation, they should keep in mind that constructing an enabling environment that minimizes these vulnerabilities will be central to any meaningful and lasting increase in the adaptive capacity of the rural poor. Govt. policies designed to promote adaptation at the farm level will lead to greater food and livelihood security in the face of changing climate.

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Participatory Soil management techniques in Rainfed agriculture

Dr.K.Nagasree
Senior Scientist (Agril .Extension), TOT, CRIDA
Email: knagasri@yahoo.com

Soil productivity depends on the physical and biological parameters an efficient management of soil conservation leading to sustainable crop production. But in most of the cases social, economic and personal factors along with community involvement influence the efficacy of the management strategies planned for soil conservation and nutrient management. Hence, it is very crucial to include the community participation for managing the natural resource like soil, water and vegetation etc.

Moreover the decentralized approach facilitates the farmer's participation right from decision making in the choice of technical interventions to implementing at the farm for optimizing the biophysical parameters resulting in sustainable agriculture production system of the communities in rural areas.

With out efforts to conserve soil and water, it would not be an easier task to sustain productivity and yield levels of Dryland crops. Effective measures therefore, need to be taken to plan and undertake soil and moisture conservation on a large scale. However the planning and implementation of conservation programmes for restoration of deteriorating resources at grass root level needs immense participation of the local village people.FAO (2000) in the guide lines for participatory diagnosis of constraints and opportunities for soil and plant nutrient management mentioned that participatory diagnosis enables the communities and the farm households to participate in the process of understanding and analyzing the existing constraints and opportunities in soil and plant nutrient management and in developing strategies for overcoming these constraints. In this context, it is essential to have the knowledge on participatory techniques and tools for mobilizing communities.. This calls out the spirit of conducting participatory exercises like PRA, (Participatory Rural appraisal,) PLA (Participatory learning Action), PRCA (Participatory Rural communication appraisal) etc,. at field level to elicit the issues and priorities by villagers.

Rapid rural appraisal or RRA developed as a methodology in the 1970s, influenced by Farming Systems Research (FSR) and other methods.

RRA was developed for quick field – oriented results with objectives as follows:

(i) Appraising agricultural and other needs of rural community;
(ii) Prioritizing areas of research tailored to such needs;
(iii) Assessing feasibility of developmental needs and action plans;
(iv) Implementing action plans, monitoring and evaluating them.

Rapid Rural Appraisal or RRA is a way of organizing people for collecting and analyzing information within a short time span. It can be defined as any systematic process of investigation to acquire new information in order to draw and validate inferences, hypotheses, observations and conclusions in a limited period of time .It has flexibility to adjust to situations because it does not imply or recommend a standard set of methods to be applied in each case.

Participatory Learning Processes

Participatory Rural Appraisal

- **PRA is a process of involving local people in the analysis and interpretation of a rural situation**

Participatory Rural Appraisal (PRA) is a methodology for interacting with villagers understanding them and learning from them. It involve a set of principles , a process of communication and a menu of methods for seeking villagers participation in putting forward their points of view about any issue and enabling them do their own analysis with a view to make use of such learning.

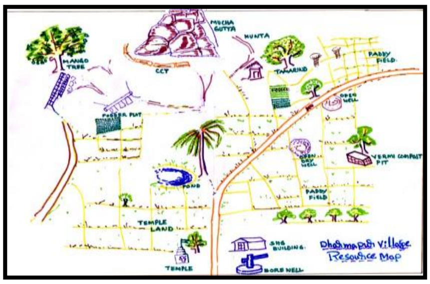
Analyzing information through People participation during PRA exercise
PRA initiates a participatory process and sustains it .Its principles and the menu of methods help in organizing participation.

Objectives of PRA

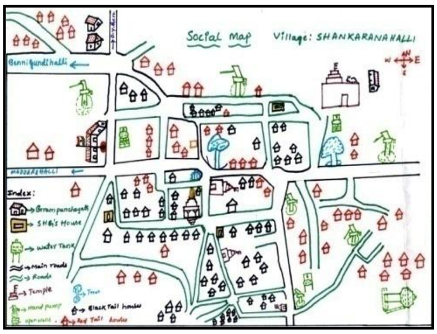
- To develop capabilities of a group/groups of people for critical analysis and assessment of their rural situations
- To build up village profile on different aspects based on perception of the local people
- To develop a system of information about the rural situation within the shortest possible time
- To ensure people's participation in programme development
- To make bureaucracy sensitive to the needs of the people

Techniques of PRA

• *Resource Map:* This indicates both the natural resources like vegetation, soil type water bodies available etc,.and man made resources needed for development of agriculture.



• *Agro-ecology Map:* Agro- ecology map will indicate the relation between agriculture and environment which includes weather parameters like rainfall, temperature, RH including fragmentation of holdings, drainage system ,weeds,etc.
• *Technology Map*: The technology map will indicate the technology decision behavior of the farmers with reference to the adoption of agricultural technologies in terms of cropping pattern, varieties , Plant protection measures and nutrient management followed etc,. giving a totality of crops situation in the village.
•*Social Map*: This is to depict the social-structure of the village like local bodies, caste structure, housing pattern Institutions organizations etc,.



• *Matrix Ranking:* Matrix ranking will indicate the reasons for technology decision behavior of the farmers., preferences of the farmers in making choice of technology etc,.
• *Mobility Map:* This will indicate the purpose for which the farmers go out for agriculture purpose.
•*Time line:* This indicates the major events remembered by the villagers and provides the past history of the village.

•*Time trend:* This indicates the change in past few years related to variables / technologies concerned with agriculture.
•*Seasonal analysis:* This indicates the month wise situation/ work operations from January to December with regard to agriculture and animal husbandry.
•*Impact diagram :* This indicates the changes that have occurred either for individual or for the society due to adoption of a technology.
•*Wealth Ranking:* Wealth ranking means placing people on the different places of social ladder according to the villagers criteria with reference to wealth status categorized by rural people themselves.
•*Livelihood analysis:* Indicates the way in which farmers belonging different category of wealth make their livelihood including the crisis management mentioning their income sources , expenditure pattern etc,.
•*Farm household Map* : This map depicts the way in which the surrounding of a typical household appears without going into the details of its inside structure .
•*Bio resources Flow Diagram* : this indicate the degree of the village household members utilize and recycle the various resources in and around the farm house to suggest remedial measures.
•*Transect* : Transact is making a long walk inside the village and locating the various items that are found in the village like soil, crops, animals, problems, etc.
•*Daily routine diagram :* This daily routine diagram depicts the way in which farmer or farm women spends his or her time from morning to night.
•*Basic information about the village :* This will indicate the data regarding the population to area under crops, number of families, yield of animals and crops, mortality related to animals etc.
•*Venn diagram :* This indicates the importance of the various individuals and the institution in and outside the village with regard to a phenomenon related to agriculture. For example getting loan for agriculture purpose.

Villagers depicting important linkages through Venn diagram

•*Problem tree:* The problem tree will indicate various resources responsible for the specific problem related to agriculture. This will also indicate the intervention for the various causes which will help in problem identification related to a discipline.
•*Preference ranking :* This is to found out the perception of farmers regarding the magnitude of the problems of agriculture found in the village.
•*ITA :* This is the indigenous technology adopted in village with reference to agriculture
•*Action Plan :*This indicates the systematic working out in board line of what needs to be done for the problems identified in the village.

- **Limitations of PRA**

  - The availability of a team with number of specialists in different disciplines and team building with the local people may be a problem
  - Perception of the job as exhaustive and time consuming, together with role reversal of learning from the local people, may develop unfavorable attitude in the specialists and officials towards the whole process.
  - The process requires expert handling by the group leader, having good field experience and knowledge of group dynamics.

- Lack of suitable accommodation in the village; vehicles for transport; equipments like camera, slide projector, video etc.; secretarial assistance may hinder the work.
- The work itself requires a good amount of fund and in spite of all efforts it may not be possible to cover more than a few villages in one season

Conclusion

Evaluation reports have shown that NRM projects cannot succeed without full participation of project beneficiaries and careful attention to issues of grass root level. "People's participation is imperative in soil and water conservation programme through watershed approach. It is a collective and cooperative effort by the local people for sharing common benefits. Participation of local people at the time of preparing a watershed development programme is very much needed to take decisions because the programme should according to the basic needs of local people. The local people are the ultimate beneficiaries of any programme. Therefore, the programme should be for the people, by the people and of the people.

THE BEST PEOPLE TO PLAN AND IMPLEMENT SOIL & WATER CONSERVATION PROGRAMMES ARE THOSE WHO USE THE RESOURCES as the community's demand for food, energy and many other needs has to depend on the preservation and improvement of the productivity of this natural resource. Participation is the key to halting degradation of soil and water and conserve them at field level. Encouraging land users to participate in conservation programmes will not be easy, however, unless those involved could participate right from analyzing rural situation through participatory processes like PRA, planning programmes, implementing and see positive gains in doing so.

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Techno-economic feasibility of Conservation Agriculture in Rainfed Agriculture[1]

C A Rama Rao
Principal Scientist (Agricultural Economics)
Central Research Institute for Dryland Agriculture, Hyderabad

INTRODUCTION

Conservation agriculture (CA) is generally referred to a way of practicing agriculture that primarily practices low tillage, incorporation of crop residues and follow up of better crop rotations (Lumpkin and Sayre, 2009). However, there are many other management practices that qualify the definition of conservation agriculture. The Food and Agriculture Organization defined the concept as 'resource saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment' (FAO, 2007). Tillage interventions are reduced to the bare minimum besides low external inputs which will lead to better biological processes in the soil (Philip et al., 2007). The widely practiced CA in terms of minimum / zero tillage, viz., zero / low tillage is predominant in South America (47%), United States and Canada (39%), Australia (9%) and the rest elsewhere. In the Indian context, CA is popular in the rice-wheat system in the Indo-Gangetic Plains and of late is getting popular in the Deccan Plateau in the rice-rice system with the second crop of rice getting replaced by maize.

Rainfed or dryland agriculture is prominent in India accounting for almost 60 per cent of the total cropped area and contributes 87.5% coarse cereals, 87.5% pulses, 77% oilseeds and 65.7% cotton of country's total production. The rainfed lands are also the areas that are prone to ill effects of climate change and experience hardships like drought and frequent crop failures. Further, the Indian climate, which is predominantly tropical and sub-tropical, encourages degradation of the land mass. In fact, the rainfed regions, especially arid and semi-arid areas particularly represented by Alfisols, Aridisols and related soil groups, are characterized by light texture, low organic carbon and low depth soils and low moisture, erratic, rainfall, soil erosion and low use of fertilizer due to poor income levels, and low productivity. Other soil groups such as Vertisols and Inceptisols also experience diversity of soil related constraints. Conservation agriculture practices can address the above constraints if adopted on a long term basis. It is therefore, all the more important in the Indian context to evaluate the necessity and possibility of CA. While for the developed economies like USA, saving the surface soils might be the prime drive for adoption of CA, however, for the developing economies, it will be the emerging agrarian concerns like shortage of water, labour and energy, deteriorating soil health and climate change.

Given the large area under rainfed agriculture which is associated with poor soils, low cropping intensity and low productivity, it would be interesting to analyze the scope and potential for different practices of CA in these areas. This paper attempts to expand the scope of CA practices besides identifying the rainfed tracts and production systems that would provide the opportunity for CA adoption. The relative economics of CA *vis-à-vis* the conventional agriculture are also compared. An attempt has also been made to assess the carbon sequestration potential.

Here is an attempt to summarize the experiments related to CA in rainfed agriculture in terms of potential gains and costs, which were estimated based on the experimental results and some assumptions. These experiments were carried out by the network of research stations under All India Coordinated Research Project on Dryland Agriculture.

The term CA which has been defined by FAO as resource conservation agricultural crop production may be expanded in our own local context for rainfed regions. Conservation of soil and water besides practices contributing towards enhancing soil health and its productive capacity must form the major components of conservation agriculture in rainfed regions. Hence, the practices for in-situ moisture conservation–contour / field bunding, conservation furrows, continuous contour trenches (CCTs), water absorption trenches (WATs), percolation tanks and water harvesting through farm ponds, energy saving during water lifting and reclying, check dams, minimum tillage, cover crops / residue application, agroforestry, vegetative cover for uncultivated lands, introduction of perennial species along with seasonal crops, organic farming, crop rotations, integrated nutrient management (INM), some components of integrated pest management (IPM) may form as components of conservation agriculture.

FINDINGS

CA in the context of rainfed area

Unlike largely homogenous growing environments of the Indo-Gangetic Plains (IGP), the production systems in rainfed arid and semi-arid areas are quite heterogeneous and diverse in respect of management of land, water management and cropping systems. The rainfed cropping systems are mostly single cropped in the red soil areas while in the black soil regions, a second crop is taken on the residual moisture. In black soils, farmers keep lands fallow during kharif and grow *rabi* crop on conserved moisture. The rainfall ranges from <500 mm in arid to 1000 mm in dry sub-humid. Alfisols, Vertisols, Inceptisols, Entisols and Oxisols are the major soil orders. Soils are sloppy and highly degraded due to continuous erosion by water and wind. Sealing, crusting, sub-surface hard pans and cracking are the key factors which cause high erosion and impede infiltration of rainfall. The choice and type of tillage largely depend on the soil type and rainfall. Leaving crop residue on the surface is another important component of CA, but in rainfed areas due to its competing uses as fodder, little or no residues are available for surface application.

The key principles of rainfed agriculture rely on soil and water conservation which are integral components of CA. Tillage in rainfed areas is mostly carried out for seed bed preparation and interculture operations for weed control and generally does not involve heavy equipment. Though conserving both soil and water are equally important in low to medium rainfall regions, more priority is given for conservation of rainfall by facilitating better infiltration and reduced runoff. That is why deep tillage once in three years is suggested to promote greater infiltration of rainwater and to control weeds. This also breaks the sub surface hard pan. However, practices like chiseling can meet the objective of breaking the hard pan without soil inversion associated with deep tillage. Experience from several experiments in the country showed that minimum or reduced tillage does not offer much advantage over conventional tillage in terms of grain yield without maintenance of adequate amount of residue on the surface (Sharma *et al*, 2009). Leaving surface residue is the key to control runoff, soil erosion and hard setting in rainfed areas which are the key problems. In view of the shortage of residues in rainfed areas in arid and semi-arid regions, several alternative strategies have emerged for generation of residues either through *in situ* cultivation and incorporation as a cover crop or harvesting from perennial plants grown on bunds and adding the green leaves as manure cum mulch. Agroforestry and alley cropping systems are other options where biomass generation can be integrated along with crop production. Thus the concept of CA has to be understood in a broader perspective in arid and semi-arid areas which includes an array of practices like reduced tillage, land treatments for *in-situ* and *ex-situ* water conservation, on-farm and off-farm biomass generation and alternate land use systems and also the energy conservation. Here, reduced or minimum tillage with residue retention on surface is more appropriate than zero tillage which is emphasized in irrigated agriculture.

Conservation tillage

As mentioned earlier, conservation tillage is more appropriate CA practice for rainfed production systems than zero tillage. The conservation tillage is considered better as it, i) allows crop residues as surface mulch, ii) is effective in conserving soil and water, iii) maintains good soil structure and organic matter contents, iv) maintains high and economic level of productivity, v) reduces the need for chemical amendments and pesticides, vi) preserves ecological stability and vii) minimizes the pollution of natural waters and environments (Lal 1989). Several experiments have been conducted to assess the impact of tillage, land treatments and mulching on the productivity of rainfed crops across the country. Under semi-arid conditions at Hyderabad, summer tillage helped in higher soil moisture retention by 20%, reduced weed infestation by

40% and contributed to higher yields (Table 2). Similarly at Jodhpur pearl millet yielded higher under conventional tillage as compared to zero tillage (Table 3). Even after eighth year of the study, conventional tillage remained superior to minimum tillage which could be attributed to more weed growth and less infiltration of water due to compaction of the surface soil under minimum tillage (Table 4). In this case, the surface residue applied @ 2 t ha^{-1} was just inadequate to create desirable soil ameliorative effect. It is anticipated that, if residue levels are enhanced, the beneficial effect of minimum tillage could be seen over years (Sharma et al, 2005).

Table 2: Effect of off season tillage on grain yields of sorghum and castor in Alfisols of Hyderabad

Practice	Sorghum grain yield*, (t/ha)	Castor bean**, (t/ha)
Without off season tillage	1.87	0.32
With off season tillage	2.60	0.31

Source: Venkateswarlu *et al* 2009; * Mean of 3 seasons; ** Mean of 2 seasons

Table 3: Yields of pearl millet under conventional and no tillage conditions under arid conditions at Jodhpur

Year	Pearl millet yield (q/ha)	
	Conventional tillage	No tillage
1995	6.48	5.84
1996	9.09	2.26
1977	7.14	2.26
1998	3.83	-

Source: Aggrawal et al (1998)

Table 4: Long-term effects of tillage and residue application on crop yields and sustainable yield index (8 years)

Residues	Sorghum (kg/ha)		Castor (kg/ha)		Sustainability Yield Index (SYI)	
	Conventional tillage	Minimum tillage	Conventional tillage	Minimum tillage	Conventional tillage	Minimum tillage
Sorghum	1127	810	820	477	0.49	0.35
Gliricidia loppings	1201	895	925	507	0.50	0.37
No residue	1103	840	840	448	0.48	0.31
Mean	1144	848	862	477	0.49	0.34
Tillage	**	**	*			
Residue	**	**	*			
T x R	NS	NS	NS			

(Source: Sharma et al, 2005); *Significant at P = 0.05, **Significant at P = 0.01, NS - Non-significant at P > 0.05

The studies so far conducted in dryland areas (Sharma *et al*, 2005; Sharma *et al*, 2009; Venkateswarlu and Sharma, 2009; Aggrawal *et al*, 1998, AICRPDA, 2009) have shown that conventional tillage gives higher yields as compared to zero tillage. However conservation tillage along with mulching with residues and INM (integrated nutrient management) gave significantly higher net returns in cotton in central India (Blaise *et al*, 2005). Conservation tillage with residue mulching is important for restoring and improving the soil health which is necessary for sustainable agricultural production. Besides conservation tillage, there are number of practices viz., intercropping systems with pulse, soil and water conservation techniques, water harvesting, selective mechanization and recycling and alternate land use systems, that similar resource conservation effects that CA has.

Vegetative cover in non-crop season

As most of the dry lands are single cropped regions, the length of growing period is around 4 to 6 months, setting aside 4 to 8 months as the off-season allowing land to be barren and exposed to weathering and soil loss. Therefore, it is imperative that some vegetation or stubbles are maintained on the soil to prevent such weathering. The potential of such measures is high in sub-humid and humid regions where the stubbles have greater chance of remaining in the same soil (Venkateswarlu *et al*, 2007).

Carbon Sequestration

Generally the rainfed lands are starved of nutrients, specifically with regard to organic carbon (OC). In majority of the rainfed lands, the OC is in the range of 0.3-0.6% on weight basis (Srinivasarao *et al*, 2009a). Low organic carbon is one of the major reasons for poor fertility of soils in rainfed regions, especially Alfisols. Carbon storage not only improves fertility but also abets global warming. Next to the forests, agriculture lands with better management have great potential for sequestering carbon. CA has one of the benefits in the form of carbon sequestration, especially through alternate land use systems. The benefits of such carbon sequestration through market participation can go to the individuals as well as to the local communities. It has been found that CA practices viz; INM under different production systems in rainfed regions sequestered significantly higher carbon as compared to farmers' practice and contribute to soil health improvement and sustainability of the system (Table 5). These suggested CA (INM) practices would also accrue carbon credits equivalent to carbon emission reduction (CER) valuing from US$ 2.84 to 11.14 per ha. In future, if CERs generated from small scale agriculture are made easily tradable these practices can generate good returns to the farmers. In present scenario, the organic resources for agriculture (FYM, compost, etc.) in the country are considered highly scarce. However, it has been estimated that the country has the potential to produce 6.24 million tones of N+P+K through organic resources if harnessed properly (Table 6).

Table 5: Carbon sequestration rate in surface soil (0-20 cm) under different production systems and soil types (t ha^{-1} y^{-1})

Production systems (soil type/ order)	Suggested CA practices	Carbon sequestration, t ha^{-1}		Potential CER from suggested CA practice	
		Farmer practice	Suggested CA practice	t ha^{-1}	Value, US $
Groundnut based (in Alfisols)	50%RDF+4 t groundnut shell ha^{-1}	0.08	0.45	0.370	7.40
Groundnut-finger millet (in Alfisols)	FYM 10 t +100% RDF (NPK)	-0.138	0.241	0.379	7.58
Finger millet-finger millet (in Alfisols)	FYM 10 t +100% RDF (NPK)	0.046	0.378	0.332	6.64
Sorghum based (in Vertisols)	25 kg N (FYM)+ 25 kg N (Urea)	0.101	0.288	0.187	3.74
Soybean based (in Vertisols)	6 t FYM ha^{-}1+ 20kg N+13 kg P	-0.219	0.338	0.557	11.14
Rice based (in Inceptisols)	100% organic (FYM)	-0.014	0.128	0.142	2.84
Pearl millet based (in Aridisols)	50% N (inorganic fertilizer)+ 50%N (FYM)	-0.252	-0.110	0.142	2.84

Based on the study by Srinivasarao *et al*., (2009b) using data from long term experiments;

CER @ US$ 20 t^{-1} which is based on the prices decided by the UNFCC (United Nations Framework Convention on Climate Change)

RDF: Recommended dose of fertilizer; FYM: Farm yard manure

Table 6: Potential of organic resources for agriculture use in India during 2000-2025

Resource/ years	**2000**	**2010**	**2025**
Generators			
Human population (million)	1000	1120	1300
Nutrients (theoretical potential) -1			
Human excreta (million t N + P_2O_5 + K_2O)	2.00	2.24	2.60
Livestock dung (million t N + P_2O_5 + K_2O)	6.64	7.00	7.54
Crop residues (million t N + P_2O_5 + K_2O)	6.21	7.10	20.27
Nutrients (considered tappable) -2			
Human excreta (million t N + P_2O_5 + K_2O)	1.60	1.80	2.10
Livestock dung (million t N + P_2O_5 + K_2O)	2.00	2.10	2.26
Crop residues (million t N + P_2O_5 + K_2O)	2.05	2.34	3.39
Total	5.05	6.24	7.75

Source: Tondon (1997); Note: Tapable = 30% of dung, 80% of excreta, 33% of crop residues

3.3 CA practices for rainfed production systems and their potential benefits

Based on the review of studies across the arid, semiarid and sub-humid regions undertaken at CRIDA, Hyderabad and of its AICRPDA centers and their ORPs over the past 30 years, we identified CA practices for different rainfalls, soil types and production systems. Net benefits at current prices from different suggested CA practices over the farmer practice under various production systems have also been estimated (Table 7).

Table 7: Suggested CA practices and their potential benefits under different production systems in rainfed regions

Rainfall (mm)	Major soil types/ order	State	Major production systems	Suggested CA practice*	Potential benefits	
					Increment in system's yield in %	Additional net returns Rs ha^{-1} $annum^{-1}$
< 500	Aridisol	Haryana, Rajasthan	Pearl millet based	• Conservation tillage (and sowing) with ridger seeder	23	1400
				• INM in pearl millet	14 - 20	535 – 750
				• Use of bullock drawn blade hoe for soil mulch creation and weed control	12	325
				• Sequence cropping with pearl millet-chickpea/raya /fallow, green gram/cowpea/ moth bean-raya *(Conserves soil and improves its quality)*	22	2000
500 – 750	Alfisols	Andhra Pradesh	Sorghum, castor based	• Formation of conservation furrow in castor	30	2100
				• INM by conjunctive use of fertilizers + green biomass of N fixing trees such as Glyricidia, N use of compost + Fertilizers (50%:50%)	15	1200
				• Intercropping with legumes (sorghum+ pigeon pea/ sorghum/ castor-horse gram *(Conserves soil and improves its quality)*	20	1700

				• Water harvesting and recycling through farm ponds ((initial capital to be given by the government through NREGS, RKVY)	15-25 *(Increase in cropped 10-15%)*	2500-4000
			Groundnut, castor based	• Legumes as inter crops as Groundnut + Pigeonpea (7:1) / Groundnut + castor (7:1).	18-20	4100-4600
				• Water harvesting and recycling through farm ponds with lining with soil + cement (6:1 ratio)	20- 24	3850 - 5000
				• Application of groundnut shell @ 5t / ha after 10 days of sowing in groundnut.	10- 15	2200 - 3500
				• Use of Rhizobium @ 500 gm/ha + 20-40-40 N, P2O5 and K_2O in groundnut	20	1800
	inceptisols	Rajasthan	Maize based	• Maize+ black gram inter cropping (2:2)	25- 40	2100-3550
				• Early rabi cropping of chick pea under Nadi system of water harvesting *(Conserves soil, higher use efficiency of harvested rainwater)*	30-35	2500 - 3200
	Vertisols	Gujarat	Groundnut based	• Set row planting of groundnut *(Conserves soil & save seed, fertilizer, labour)*	15	2800
				• Use of enriched compost (6 t ha^{-1})	15- 23	1600 - 2700
				• Recharging open wells through filters (*Retains 67% sediment load and enhance ground water level)*	15-30	1400-2500
				• Growing of suitable cropping systems Groundnut + castor (3:1)/Groundnut + Pigeon pea (3:1), cotton + Green gram (4:1)	15-20 *(as compared to sole crop)*	1700-2300
		Tamil Nadu	Cotton based	• Compartmental bunding and balanced nutrition in rainfed cotton	20-28	2000-3200
				• Dust mulching (soil stirring) *(Increases in-situ moisture conservation)*	8-10	1200-1500
				• *Ailanthus (Helianthus) excelsa* based silvi-agri system *(Higher carbon sequestration, conserves soil and water)*	15-40	2500-6000
		Maharashtra	Rabi sorghum based	• Compartmental bunding in rabi sorghum	15-20	1500-2100
				• Ridge and furrow for in-situ moisture conservation *(Conserves 45% more moisture)*	15-30	1400-3000
				• Intercropping of pearl millet + pigeon pea (2:1), sunflower + pigeon pea (2:1), castor + cluster bean etc.	25-30	2500-3000

				• Two-bowl ferti-seed drill for efficient sowing of rainfed crops *(Higher nutrient use efficiency, labour saving)*	20-25	1500-2200
				• 50% N through crop residue (sorghum/leucaena) + 50% N through fertilizer to rabi sorghum	20	1400-1500
		Karnataka	Rabi sorghum based	• Compartmental bunding	30-40	4500-7500
				• Cover cropping with pulse crops *(Conserves soil and water, improves soil quality)*	20-25	2200-3000
				• Inter plot rain water harvesting	25	4500-7000
	Entisol	Uttar Pradesh	Pearl millet, mustard based	• Ridge planting of pearl millet	20-30	2200-3000
				• Deep tillage and compartmental bunding	15	1400-1800
				• INM through 50% fertilizer N + 50% FYM N	20	1500
	Aridisol	Gujarat	Castor, pearl millet based	• Compartmental bunding in pearl millet	20	500-800
				• Suitable cropping system Green gram + pearl millet (3:1), Cowpea + castor (2:1), sorghum + karingdo (6:1), pearlmillet + cluster bean (2:1)	20-25	800-2500
				• Silvi-pasture system (amala+ Dichanthium annulatum) *(Conserves soil and water, improves soil quality, higher carbon sequestration, supply fodder)*	15-20 *as compared to sole Amla*	4000-5000
750 – 1000	Alfisol	Karnataka	Finger millet based	• Finger millet + pigeon pea intercropping (10:2)	15	3000-4000
				• Bud nipping in rainfed castor	15-28	2400-3600
				• Graded border strips in deep red soils	15	1800
				• Rainwater harvesting and recycling through lined farm pond *(Initial capital to be given by the government through NREGS, RKVY, etc.)*	15-20 *+ 10-15% more cropped area mostly under vegetables and cash crops*	2500-7000
	Vertisol	Madhya Pradesh	Soybean based	• Raised and sunken beds (8:4 m wide with elevation difference of 0.15 to 0.20m) *-Very effective in in-situ moisture conservations and controlling nutrient and soil losses*	20-25	2500-3200
				• Straightening of gullies to reduce the length of the gullies.	10	1000-1200

				• Water harvesting through ponds *(initial capital to be given by the government through NREGS, RKVY, etc.)*	20-40 *Diversification into flori-horticulture*	8000-10000
		Maharashtra	Cotton based	• Intercropping system : cotton + sorghum + pigeonpea + sorghum (6:1:2:1) *(Ensures fodder, risk resilient, conserves soil and rainwater)*	22	1500
				• Rainwater harvesting and recycling through farm ponds *(Initial capital to be given by the government through NREGS, RKVY, etc.)*	20-25 *+ 15-20 % increment in cropped area*	5000-9000
				• *In-situ* moisture conservation through top sequence based cropping *(Conserves soil, water and saves energy, reduce tillage)*	20-25	4000-5000
				• Application of 5 t of FYM + 40 kg P_2O_5 + microbial culture @ 1.5 kg/ha to pigeon pea	25	3200
	Inceptisols	Uttar Pradesh, Bihar	Paddy based	• Power operated till planting for sowing of crops in rice fallows *(Reduce tillage, use residual moisture, saves time)*	15-19	6000-7500
> 1000	Inceptisols	Jammu & Kashmir,	Maize based	• Agri-horti (amla-guava + gobhi sarson in rabi or maize in kharif) and agri-silvi (subabul + gobhi sarson in rabi or fodder maize in kharif) systems	20-50	3000-5000
				• Rainwater harvesting and recycling through farm pond *(Initial capital to be given by the government through NREGS, RKVY, etc.)*	25	3500
		Punjab	Maize based	• Tractor operated seed cum ferti drill. *(Reduction in tillage)*	15-20	3500-5000
				• Staggered or continuous contour V tracks made at suitable vertical intervals for soil and water conservation *(Conserves soil and rainwater)*	15-20	2500-3600
		Uttar Pradesh, Bihar	Paddy based	• Ridge and furrow system in case and diversification of rice-wheat cropping system into rice-pigeon pea system *(Cost reduction, improves soil health, conserves rainwater)*	15-20	12000-18000
	Oxisols	Jharkhand	Paddy based	• Rainwater harvesting and recycling through farm pond *(Initial capital to be given by the government through NREGS, RKVY, etc.)*	30-50	10000-16000

				• Intercropping : pigeonpea + rice (1:3) / pigeonpea + maize (1:1) / pigeonpea + groundnut (1:2	30-35 *as compared to sole crop*	7000-10000
		Orissa	Paddy based	• Maize + pigeonpea intercropping system (1:1)	20-30	6000-9000
	Vertisols	Madhya Pradesh	Paddy, soybean based	• Soybean + pigeon pea inter cropping	30-40	5000-8000
				• Rainwater harvesting and recycling through farm pond *(Initial capital to be given by the government through NREGS, RKVY, etc.)*	20-25 *Higher diversification*	5000-7000

* Identification of suggested CA practices and net benefits there from are based on long term research experiments of CRIDA (Venkateswarlu et al, 2009; AICRPDA, 1991-2009; Srinivasarao *et al*, 2009a &b; Sharma *at al*, 2009) and a brainstorming session involving a group of scientists working in the relevant area.
Note: INM practice of applying 50% N through organic + 50% N through inorganic fertilizers is suggested for every production system

The above analysis clearly demonstrates that the suggested CA practices viz., Rainwater harvesting and recycling for supplemental / critical / come up irrigation, recharging of open wells/borewell for efficient recycling, location specific inter-terrace land management, in-situ moisture conservation, integrated Nutrient Management and balanced nutrition, seed cum fertilizer drill, mechanized weeding and inter-culture operations, alternate land use with efficient agro-forestry systems, reduced tillage with residue mulching and chemical weed control, for various production systems in different soil and rainfall situations not only improves system's productivity and sustainability but also significantly enhances net returns per ha over the existing farmer practice (Table 7). However it would be necessary to put appropriate policy and institutions in place and make suitable technological options available for promoting adoption of suggested CA practices (Table 8). Many CA practices like rainwater harvesting through farm pond and its recycling are both capital and labour intensive, which resource poor farmers in rainfed areas may not be able afford. In a study of adoption of CA practices in ORPs under AICRPDA network centers (Ravindra Chary et al, 2009), it was summarily inferred that non-adoption of CA practices/ NRM technologies was mainly due to lack of proper intuitional and policy support.

Table 8: Conditions to be met for adoption of CA

CA practices/ interventions	Policy and institutional needs	Technology needs
Rainwater harvesting/ farm ponds	• Initial investment has to come from the government by converging different schemes like MNREGS/ RKVY/ NFSM/ watershed programmes etc. • Operationalization of farm ponds needs to be done as a customized package for water harvesting and utilization (including inlet and outlet pitching, lining, water lifting, micro-irrigation system, etc.)	• Low cost and easy to handle water lifting devices and micro irrigation system matching the needs of different category of farmers.
Integrated nutrient management (conjunctive use of organic and inorganic fertilizers, residue management,	• Arrangements in place for capacity building • Policy favouring promotion of organic supply of nutrient in terms of crop residue management and higher biomass production for mulching particularly in fragile soil environs. • Convergence with RKVY, NHM, etc may be	• Location specific on-farm demonstrations on a large scale.

mulching through biomass	useful.	
In-situ moisture conservation	• Identification of appropriate *in-situ* moisture conservation practices (ISMCP) on agro climatic zone basis and further narrowing down to district/block/ tehsil level. • Need to be implemented as an area approach by converging with relevant programmes like MNREGS/RKVY/watershed programme covering all categories of farmers cultivating marginal/ fragile lands/soils. • Need to improve access to implements for wider scale adoption of ISMCPs through custom hiring services promoted by self help groups and or subsidy.	• Large scale on-farm demonstrations • Launching awareness campaign • Appropriate implements (bullock drawn/ tractor drawn) need to be identified/modified/ developed.
Alternate land use systems (ALUS)- Silvi-agri, horti-agri and agro-forestry systems	• Capacity building of the stakeholders • Single window delivery system of support for promoting ALUS starting from land preparation to stage when ALU begins to give economic benefits. Convergence among MNREGS, NHM, and watershed programme may help in this.	• Delineate suitable areas for promoting ALUS considering local resources, traditional skills, market opportunities, fodder supply, carbon credits and value addition options.

Steps to promote conservation agriculture in drylands

1. There is a need to create awareness among the communities about the importance of conservation of land/soil resources and organic matter buildup in soil. Traditional practices such as burning of residues, clean cultivation, intensive tillage and pulverization of soil up to the finest tilth need to be discouraged. Electronic media support at large scale is must to convey these aspects to the farmers / communities.
2. Systems approach is essential for fitting conservation tillage in modern agriculture. In order to follow the principle of "grain is to man and residues are to soil", farming systems approach introducing alternative fodder crops is essential. Agroforestry systems with special emphasis on silvipasture systems need to be introduced. Unproductive livestock herds needs to be discouraged
3. For the adoption of conservation tillage, it is essential that complete package of practices may be identified for each agro ecological region.
4. The increased use of herbicides has become inevitable for adopting conservation tillage/conservation farming practices. The countries that use relatively higher amount of herbicides are already facing problem of non-point source pollution and environmental hazard. In order to reduce the herbicidal demand, there is need to improve crop husbandry practices that suppress weeds.
5. The conservation farming also has objective to minimize the inputs originating from non-renewable energy sources. E.g. Fertilizers and pesticides. Hence, research focus is required on enhancing fertilizer use efficiency and reduction in use of pesticides. This aspect can be strengthened by following integrated nutrient management (INM) and integrated pest management (IPM) approach.
6. Inter-disciplinary research efforts are required to develop appropriate implements for seeding in zero tillage, residue incorporation and inter-cultural operations.
7. Initially conservation agriculture practices especially zero / reduced tillage may result in reduced yields over conventional tillage, but catch up with the later over time. Hence, initial incentives are important to motivate the farmers to follow conservation tillage
8. To protect the soils from further degradation, several steps such as protection of top soil from erosion, reorientation of soil testing program in the country, promotion of organic matter build up and integrated

nutrient management, balanced multi-nutrient fertilization, amelioration of problematic soils using suitable amendments , surface land cover management etc are emphasized

9. Research and management strategies and appropriate policies are required to be formulated to improve soil quality embedding conservation agricultural principles. After all, protection of land resource is an investment for future. This aspect must from the part of National Agenda and priority in National Five Year Plans. A National Mission on Conservation Agriculture akin to national horticulture mission may be created in the XII five year plan.

CONCLUSIONS

The analysis in the paper amply shows that conservation agriculture in its broader sense not only improves soil health but also gives higher net returns per unit of land to the farmers. However, the CA practices need to be adapted selectively in different rainfall, soils and agro ecological situations. The minimum tillage in rainfed areas initially may not be an attractive practice as it results into hard setting due to less loosening of soil and consequently low infiltration of water in the profile and excessive weed growth. But, there are indications that a better advantage of reduced tillage could be accrued, if reduced tillage is accompanied by surface residue application and appropriate weed management. Besides these, other conservation agricultural practices such as appropriate soil water conservation measures, integrated nutrient management, use of compost and vermicompost, recycling of crop residues, green manuring and use of green leaf manures, crop rotation with legumes and cover crops have proved quite effective in enhancing the sustainability of the yields and improving soil quality across the rainfed agro-ecologies. Thus, the advantage of conservation agricultural practices can be availed in rainfed agro-ecology, if practiced over a long period. In the context of CA, there is need for a paradigm shift in the thinking of the farmers, burning of residues, clean cultivation, intensive tillage and pulverization of soil up to the finest tilth need to be discouraged. Higher carbon sequestration through CA practices may also give additional benefits in terms of CERs if made tradable in future. However to further enrich our understanding, there is need to undertake in-depth micro-level studies on impact of CA in different agro climatic zones. For promotion of CA practices across diverse agro-ecologies, appropriate policy and institutional support would be a prerequisite. Convergence of various schemes viz., MNREGS, NHM, RKVY, etc. at local level involving all major stakeholders would surely contribute towards promotion of CA in rainfed regions. In devising appropriate policies relating to CA and, more generally, sustainable agriculture, there is a need for improved policy analysis and information for decision making. Developing sustainability indicators that can more clearly show the benefits of CA over its alternatives is one step. Similar improvements are achievable at the economic-analysis level. For example, incorporating the depletion of natural capital in studies of conventional farming practices can help evidence the limitations of these techniques. Ultimately, a whole-farm systems approach may be the most appropriate basis for financial analyses of CA, as this can capture the full range of responses that farmers make when choosing to adopt a new technology such as CA.

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"Climate Resilient Agricultural Practices – TDC experiences under NICRA"

Y.G Prasad
Director, ICAR-Agricultural Technology Application Research Institute, Hyderabad ygprasad@gmail.com

ICAR launched a nation-wide project "National Initiative on Climate Resilient Agriculture (NICRA)" in 2011 to carry out basic, applied and strategic research to address climate change and climate variability and work towards imparting resilience to Indian agriculture. As part of this initiative, the Technology Demonstration Component (TDC) addresses the issues of enabling farmers through demonstration of available location-specific climate resilient practices and technologies. The demonstrations related to natural resource management, crop production, livestock and fisheries offer an integrated package of proven, location-specific technologies for adaptation of the production systems to climate variability. TDC is under implementation in a farmer participatory mode in 130 vulnerable districts of the country through 121 Krishi Vigyan Kendras (KVKs) and 7 TOT divisions of ICAR research institutes.

The demonstrations are categorised broadly under four different modules viz., natural resource management, crop production, livestock and fisheries and institutional interventions. To facilitate their effective implementation, various institutional mechanisms were also established at the village level.

Natural Resources

This module consists of interventions related to water harvesting and recycling for supplemental irrigation, improved drainage in flood prone areas, conservation tillage where appropriate, artificial ground water recharge, and efficient water management methods. Over 800 Rain Water Harvesting (RWH) structures were constructed, renovated, or repaired in the project. An additional rainwater storage capacity of two lakh cu.m was created through farm ponds alone.

Crop Production

This module consists of introducing adaptation technologies and practices to impart resilience to crop production. The interventions include demonstration of short duration drought or flood tolerant crop cultivars, contingency crop planning, soil test based nutrient application, water saving methods (direct seeding), advancement of planting dates of rabi crops in areas with terminal heat stress, in situ moisture conservation and crop diversification.

Institutional Interventions

This module consists of institutional interventions by either strengthening the existing ones or initiating new ones especially an innovative farm machinery custom hiring centre (CHC). Timeliness of agricultural operations is crucial to cope with climate variability, especially with sowing and intercultural operations. Custom hiring centre for agricultural implements could successfully empower farmers in 100 NICRA villages to tide over the shortage of labour and improve efficiency of agricultural operations. A committee of farmers' nominated by the gram sabha known as Village Climate Risk Management Committee (VCRMC) manages the custom hiring centre. The rates for hiring the machines/ implements are decided by the VCRMC. This committee also uses the revenue generated for repair and maintenance of the implements and remaining amount goes into revolving fund. Seed and fodder bank are also taken up by the committee or commodity groups.

Land shaping for rainwater harvesting, utilization & integration of farm enterprises: In order to overcome submergence during *kharif*, salinity problem in *rabi* and augment availability of irrigation water during the *rabi*-summer season, an engineering solution was promoted by the KVK, scientist. The excavated soil was spread over the adjacent field area (80%) so as to raise the field level up to 1 to 1.5 feet and also to raise the field border embankments of land. Fish and duck rearing were introduced in the harvested freshwater in the pond. Thus, this technology of land shaping offered a model for harvesting rainwater in *kharif*, vegetable cultivation during *rabi* and fresh water fish culture in the ponds.

Establishment of community paddy nursery: Establishing a staggered community nursery was explored as a local adaptation strategy at the village level to combat the problem experienced by farmers during deficit rainfall seasons in lowlands. The technique involves raising a staggered community nursery under assured irrigation in the village at an interval of 2 weeks. In the anticipation of a two weeks delay in monsoon the first nursery is taken up as a contingency measure by 15 June with the long duration variety (>140 days) in order to transplant 3-4 weeks old seedlings by first fortnight of July. If the monsoon delay extends by 4 weeks, the second nursery is raised with medium duration varieties (125-135 days) by 1st July to supply 3-4 weeks old seedlings for transplanting in the 3rd or 4th week of July. In case of anticipation of further delay or deficit rainfall conditions, the 3rd nursery is raised by mid July with short duration varieties (<110 days) to take up transplanting of 3-4 week seedlings in the first fortnight of August.

Direct seeded rice in un-puddled field to cope with water shortages: Direct seeding of drought tolerant varieties of rice in dry soil is done in June with pre-emergence herbicide application (pendimethalin 1 kg/ha) under sufficient soil moisture conditions followed by a post-emergence herbicide application (bispyribac sodium 25g/ha) at 25-35 days after sowing or hand weeding at 35-45 days after sowing to effectively manage weed problem. Direct seeding of rice is done with a zero till drill. The quantity of seed required is 20- 25 kg/ha compared to transplanted paddy which requires 60-80 kg/ha.

Drum seeding of rice for water saving and timeliness in planting: Drum seeding technique involves direct seeding of pre-germinated paddy seeds in drums made up of fiber material to dispense seeds evenly in lines spaced at 20 cm apart in puddled and levelled fields. About 35 to 40 kg paddy seed/ha is soaked overnight in water and allowed to sprout. Care should be taken not to delay sowing as seeds with long shoot growth are not suitable for drum seeding. The sprouted seed is air-dried in shade briefly (<30 minutes) prior to sowing for easy dispensing through the holes in the drum seeder.

Drought tolerant paddy cultivars to tackle deficit rainfall situations: Short duration and drought tolerant varieties that can withstand up to 2 weeks of exposure to dry spells in rainfed areas were demonstrated in NICRA villages. Drought tolerant cultivars demonstrated in farmers fields include: 'Sahbhagi dhan' (105-110 days duration in plain areas and 110-115 days in uplands, highly resistant to leaf blast and moderately resistant to brown spot and sheath blight. 'Naveen' (115-120 days duration and 'Anjali' (90 days). Other early maturing varieties that have potential in the eastern states include: 'Birsa Vikas Dhan 109' (85 days duration), and 'Abhishek' (120 days duration).

Short duration finger millet varieties for delayed monsoon / deficit rainfall districts in south interior Karnataka: When the delay in monsoon is about 4 weeks, medium duration varieties like GPU-28 (110 days duration) performed better while in case of further delay, short duration varieties like ML-365 (105 days) and GPU-48 (100 days) performed better. These short duration varieties of finger millet are also tolerant/ resistant to blast disease and can be sown till August under rainfed conditions in medium to deep red soils.

Crop diversification for livelihood security and resilience to climate variability: Pigeonpea, cotton, sunflower and sorghum are the main crops cultivated in NICRA village in Kurnool district. These crops are affected due to late onset of monsoon followed by dry spell at critical crop growth stages. Intercropping of Setaria (foxtail millet, SIA-3085 variety) with pigeonpea (5:1 ratio) sown in July showed that the intercropping system was more profitable with highest benefit cost ratio in all the 3 years despite prolonged dry spell of up to 25 days. In other semi-arid agro-ecosystem, intercropping of soybean + pigeonpea (4:2), pearlmillet + pigeonpea (3:3), pigeonpea + green gram (1:2) and cotton + green gram (1:1) performed significantly better than their sole crops in case of deficit rainfall conditions.

Flood tolerant varieties impart resilience to farmers in flood-prone areas: Rice varieties Swarna-sub1, MTU-1010, MTU-1001 and MTU-1140 are high yielding with good grain quality apart from possessing submergence tolerance and perform better under flood situation. Demonstration of these varieties in flood-prone areas showed that Swarna-sub1, a variety developed by IRRI and CRRI, Cuttack and released in 2009, could tolerate submergence up to two weeks and could perform significantly better compared to other improved and local cultivars. MTU-1010 is a short duration, dwarf variety resistant to lodging and can withstand moderate wind velocity. This attribute of lodging resistance saves from not only loss in grain but also straw yield which is the main source of dry fodder. MTU- 1140 is also a promising, non- lodging variety comparable in grain quality to BPT-5204, which performed well in flood-prone villages in Srikakulam district of Andhra Pradesh.

Community tanks / ponds as a means of augmentation and management of village level water resources: One of the first works accomplished in NICRA villages was to identify these structures to carry out desiltation with farmer's participation. The rich silt deposited in these structures was used by farmers for spreading in the fields, wherever necessary, to improve the water holding capacity of soils. This intervention helped in increasing the surface water resource availability, increased the ground water recharge observed through water table measurements in wells located nearer to the tanks.

Individual Farm pond for improving livelihood of small farmer: One way to cope with climate vulnerability is to collect rainwater in harvesting structures to increase the irrigated areas as well as crop productivity. Farm ponds have been considered as one of the key interventions in NICRA villages in Karnataka, Telangana, Andhra Pradesh and Maharashtra and have been widely adopted in the villages. Various cropping system modules were worked out by using harvested water. Majority of farmers opted to cultivate vegetables with harvested water in a ratio of 1:10 (command to catchment area) with sustained profits.

Low Cost water harvesting structure-Jalkund: The shortage of water can be minimized by rainwater harvesting and its judicious use for crop production. Direct rainfall collection through water catch ponds/pits (Jalkund) or storage by diverting runoff can be highly beneficial to farmers for providing irrigation to crops during moisture scarcity conditions during dry seasons. Rainwater can be stored directly in *Jalkunds* during the rainy season which can be utilized to provide protective irrigation to the crops for successful cultivation.

Storing excess runoff in streams through check dam: *Ex-situ* storage of water in seasonal streams at suitable sites is an important strategy to conserve excess runoff water in different rainfall zones. Often, by virtue of the location with reference to nearby hilly areas, the village may receive copious amounts of surface runoff from surrounding areas. This excess runoff could be harvested in streams either for direct use or for improving the ground water availability. In high rainfall areas, though runoff availability is high, often it gets lost due to non-availability of storage structures. In these regions, on-stream storage structures could be built on first order streams to make water available for direct use during long dry spells by farmers. In majority of NICRA villages, check dams (new/desilting of existing ones) were major interventions in drought prone districts in different rainfall zones.

Sand Bag Check dam: Rainwater harvesting and recycling was demonstrated by construction of temporary check dams. Temporary check dams were constructed by using low cost gunny/ polythene bags. These bags were filled with sand from stream beds. The sand filled bags were placed one above the other in two or more rows. The gap between two rows was filled with clay to check water leakage. An outlet was provided to each dam to allow excess water to flow downstream. These check dam helps in ground water recharge and rising of water table in the area. Harvested water in the temporary check dams is used for life saving irrigation in *rabi* and summer crops.

Recharge of wells: Recharging of tube wells was taken up as a major intervention. The technique involved diverting runoff to a pit dug around the tube well after trapping the silt. About 8 to 10 cement rings were descended into the dugout around the tube well. Harvested rainwater is collected in a cement tank and allowed for the silt to settle down and then conveyed to the dugout using a PVC pipe. Material required for recharging included cement rings (8-10 numbers, 4.5 ft radius, 2 ft height), bricks (500), cement (1 bag), pipe (10 ft long) and one perforated pipe (6ft long). Average cost incurred was Rs.10,000 out of which 25 per cent of total cost and labor was shared by the farmer.

Integrated Farming Systems: Several integrated farming system modules with a combination of small enterprises such as crop, livestock, poultry, piggery, fish and duck rearing were demonstrated to farmers in NICRA villages in the eastern, northern, north eastern and southern states where monocropping is mostly practiced due to climatic conditions.

Captive rearing of fish seed - a livelihood opportunity in flood-prone areas: Captive rearing of fish seed i.e. rearing of early stages (spawn to fry and fry to fingerling stages) through appropriate feed and health management in nursery pond was demonstrated in Sirusuwada village, Kothur mandal of Srikakulam district, Andhra Pradesh. Required training for captive rearing was provided to the fisher folk by the KVK. The practice brought about self-reliance along with reducing costs and increasing returns by adequate stocks in main tanks.

Management practices to tackle cold stress in backyard poultry: A brooder house was made using locally available materials such as bamboo and wood and to maintain optimum night temperature in the shelter with the help of light bulbs during cold stress period. Breed improvement was made with the introduction of Gramapriya and Vanaraja chicks in NICRA villages. The movement of chicks was restricted nearer the heat source in brooder house with the help of chick guards made with card board. The chicks were fed with ground maize initially, later fed with vegetable wastes and other kinds of locally available grains like maize and rice bran besides the feed material available from free range scavenging as they grew up. Wholesome fresh water was made available at all times in the watering and feeding trough made of bamboo. Chicks were also supplemented with multivitamins @ 1ml /lt of water.

Shelter management: A semi-intensive system of rearing of goats in a slatted floor with proper roof can provide shelter to the animals to tackle heat stress during summer and rain storms during monsoon. Locally available wooden planks were used for making slatted floor. A gap of one inch was maintained between each slat so that the urine and fecal material could be collected from the bottom of the floor. The roof of the shelter was made with bamboo and covered with either thatched material or coarse cereal crop residues. The improved shelter reduced kid mortality and increased profitability.

Improved planting methods for enhancing water use efficiency and crop productivity: There is a need for *in-situ* soil and water conservation and proper drainage technology in deep black soils. Broad bed and furrow (BBF) system involves preparation of a broad bed of 90 cm, furrow of 45 cm and sowing of crop at a row spacing of 30 cm. The cost of BBF implement is Rs. 45,000. The BBF technology has many advantages including *in-situ* conservation of rainwater in furrows, better drainage of excess water and proper aeration in the seedbed and root zone. More than 200 farmers in Sanora and Barodi village in Datia district of MP adopted the technology. Similarly, furrow irrigated raised bed (FIRB) planting was promoted for cultivation of different crops in several states viz., Uttar Pradesh, West Bengal, Punjab, Maharashtra, Karnataka, Rajasthan and Tamilnadu. Ridge and furrow method of vegetable cultivation was promoted in Gumla district and in cotton at Amravati and Aurangabad, Maharashtra.

Zero till planting of rabi crops: Demonstrations of zero till drill sown wheat in farmers' fields were undertaken in several NICRA villages in Punjab, Haryana and Uttar Pradesh. The zero till drill not only saved tillage costs and energy but also eliminated the need for seedbed preparation. Zero till drilled wheat yields were on par with conventionally sown wheat. The machine operated with a 35 hp tractor to cover sowing of wheat in 4-5 ha/day.

In situ incorporation of biomass and crop residues for improving soil health: In order to encourage farmers to change this practice, rotavator machine was introduced in several NICRA villages. The harvested crop stalks/ stubbles are chopped into small pieces and incorporated *in-situ* into the soil with varying efficiencies depending upon the left over residue. The cost of implement is Rs. 1.0 to Rs.1.2 lakhs and field capacity of the rotavator is 5-6 ha/day. Rotavator helps in obtaining of early seedbed preparation soon after harvesting of *kharif* crops for sowing of *rabi* crops. This not only requires low energy in tillage operation but also mixes and incorporates the stubbles of previous crop thoroughly in the soil. This improves the soil physical properties and hence, results in increased crop yield. Incorporation of green manuring crops such as daincha, moong and cowpea in wet conditions can be taken up to improve soil health.

Village level seed banks to combat seed shortages: Participatory village level seed production of short duration, drought and flood tolerant varieties was demonstrated in several NICRA villages with the support of KVKs in rice, soybean, groundnut, greengram, finger millet, foxtail millet and pigeonpea. Breeder seed / foundation seed was sourced from research farms for multiplication in farmers fields and the quality seed so produced was mostly used in the village and nearby villages. Farmer to farmer sale as truthful seed was the means of spread.

Fodder cultivars to tackle fodder scarcity: Short and medium duration fodder cultivars of several crops that can withstand up to 2-3 weeks of exposure to drought in rainfed areas were demonstrated in NICRA villages. These include: sorghum (Pusa Chari Hybrid-106 (HC-106), CSH 14, CSH 23 (SPH-1290), CSV 17); Bajra (CO 8, TNSC 1, APFB 2, Avika Bajra Chari (AVKB 19); Maize (African tall, APFM 8). These cultivars can be sown immediately after the rains under rainfed conditions in arable lands during *kharif* season and are ready for cutting by 50-60 days. Cultivars of *rabi* crops like Berseem (Wardan, UPB 110) and Lucerne (CO 1, LLC 3, RL 88) were demonstrated in NICRA villages as second crop with the available moisture during winter. Perennial fodders like APBN-1, CO-3 and CO-4 were also demonstrated under limited irrigated conditions.

Way Forward: Climate resilient agricultural practices need to be adopted widely by farmers for risk management and enhancing adaptive capacity. This needs awareness creation and exposure through participatory technology demonstrations. Various barriers for adoption such as lack of adequate support for timely availability and access to resources, machinery and inputs need to be effectively addressed. Some of these practices can be scaled-up and scaled-out with support from various ongoing government schemes such as the National Mission on Sustainable Agriculture and Green Climate Fund.

Further reading:

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