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Technological Interventions for Enhancing Farm Productivity in Salt-affected *Vertisols*

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Preface

The problems of environmental degradation in salt-affected *Vertisol* regions of Gujarat are as diverse and complex as the ecological fabric of the state. While some of the problems are widespread and operate over long term the others are mainly localized and more intensive in their impacts. Vast areas are in imminent danger of turning barren and production and productivity have simply declined due to secondary salinization. Soil salinity problems are further compounded where the ground water is highly saline and such areas *by and large* remain barren for want of economically feasible technological interventions and thereby affecting the livelihood of the farmers because of low productivity of the existing farming practices.

To make agriculture viable and sustainable in these environments, improved technologies such as soil management, use of poor quality water, selection of crops/varieties to suit the environment, suitable agro-techniques including water management and irrigation technologies, water conservation measures through appropriate rainwater harvesting strategies and farming system studies thus assume significance. An attempt has been made to compile some of the important technological interventions to enhance farm productivity and productive utilization of the resources in these regions.

We gracefully acknowledge the receipt of financial assistance from Gujarat State Bio-Technology Mission (GSBTM), Gandhinagar for printing this publication.

We sincerely hope that this manual will be of use to farmers, officials of line departments as well as researchers which will assist in enhancing farmers' incomes and livelihood eventually leading to the systematic development of agriculture and allied sectors of salt-affected *Vertisol* regions.

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Reclamation and Management of Salt Affected Soils for Increasing Farm Productivity and Farmers' Income

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Introduction

Soil salinity is one of the main environmental problems affecting extensive areas of land in both developed and developing countries. Salinity is common in the region of arid and semi-arid regions where rainfall is too low to maintain a regular percolation of rainwater through the soil and irrigation is practiced without a natural or artificial drainage system. Such irrigation practices without drainage management trigger the accumulation of salts in the root zone, affecting several soil properties and crop productivity negatively. Globally, more than 900 million hectares (M ha) of land, accounting for nearly 6% of the world's total land area and approximately 20% of the total agricultural land is affected by salinity (Ghassemi *et al*., 1995). Salinity is the product of complex interaction of many variables which lessen the current and/or potential capability of soil to produce goods and services. Presently, the total degraded land due to salinity and sodicity is estimated to be 6.74 M ha in India (Table 1) (NRSA and Associates, 1996) of which 2.22 M ha is present in Gujarat State (Table 2) and about 0.12 M ha area is affected by salinity in black soil region of Gujarat covering Bara tract area (Amod, Vagra and Jumbusar taluka of Bharuch district), Bhal area and part of Vadodara, Surat and Ahmedabad districts.

The problems of environmental degradation in Gujarat state are as diverse and complex as the ecological fabric of the state. While some of the problems are widespread and operate over long term the others are mainly localized and more intensive in their impacts. Soil salinity problems are further compounded where the ground water is highly saline and such areas *by and large* remain barren for want of economically feasible technological interventions and thereby affecting the livelihood of the farmers because of low productivity of the existing farming practices. The adverse effects of salinity have put the food and nutritional security at stake besides creating environmental pollution and affecting soil health and income of the farmers.

Soil salinity

Concentration of soluble salts in the surface or near-surface soil horizon is a major problem with severe worldwide economical and social consequences. In terms of agricultural consequences, an excessive salt in soil accelerate land degradation processes resulting in increased impact on crop yields and agricultural production and ultimately leads to lower the farmers' income. Accumulation of soluble salts at the surface or near-surface of soil horizon is called salinization (Szabolcs, 1974). As a consequence, chlorides and sulphates of sodium, calcium and magnesium increase in their concentration resulting in increased electrical conductivity (EC). Further, presence of salt crystals, salt crusts and salic horizons result in presence of loose and quite porous granular structure in the top soil. The top soils become puffy in the presence of large amounts of sodium sulphate and appear moist when soils have calcium chloride and magnesium chloride.

Natural or primary salinity

Salinity, primarily results from the accumulation of salts over long period of time, in the soil or groundwater, which is generally caused by two natural processes.

- The first is the weathering of parent materials containing soluble salts which break down rocks and release soluble salts of various types, mainly chlorides of sodium, calcium and magnesium, and to a lesser extent, sulphates and carbonates. Sodium chloride is the predominant soluble salt.

- The deposition of oceanic salt carried by wind and rain forms the second cause. 'Cyclic salts' are ocean salts carried inland by wind and deposited by rainfall, and are mainly sodium chloride.

Table 1. Extent (ha) of salt affected soils in different states of India

State	Saline	Sodic	Total
Andhra Pradesh	77598	196609	274207
Andaman & Nicobar Island	77000	0	77000
Bihar	47301	105852	153153
Gujarat	1680570	541430	2222000
Haryana	49157	183399	232556
Karnataka	1893	148136	150029
Kerala	20000	0	20000
Madhya Pradesh	0	139720	139720
Maharashtra	184089	422670	606759
Orissa	147138	0	147138
Punjab	0	151717	151717
Rajasthan	195571	179371	374942
Tamil Nadu	13231	354784	368015
Uttar Pradesh	21989	1346971	1368960
West Bengal	441272	0	441272
Total	2956809	3770659	6727468

Table 2. Extent (ha) of salt affected soils in different districts of Gujarat

District	Saline	Sodic	Total
Ahmadabad	161479	116428	277907
Amreli	42952	0	42952
Banaskantha	211722	83240	294962
Bharuch	62561	0	62561
Bhavnagar	78414	21249	99663
Jamnagar	82389	13389	95778
Junagadh	39800	69358	109158
Kheda	37852	0	37852
Kachchh	607336	13430	620766
Mehsana	117684	126077	243761
Rajkot	57634	0	57634
Surat	26287	0	26287
Surendranagar	135170	98259	233429
Vadodara	3863	0	3863
Valsad	15427	0	15427
Total	1680570	541430	2222000

Secondary or human-induced salinity

- Salinity occurs through natural or human-induced processes that result in the accumulation of dissolved salts in the soil water to an extent that inhibits plant growth. Secondary salinisation results from human activities (anthropogenic) that change the hydrologic balance of the soil between water applied (irrigation or rainfall) and water used by crops (transpiration).

Sources and causes of accumulation of salts

The main causes of salt accumulation include:

- Capillary rise from subsoil salt beds or from shallow brackish ground water;
- Indiscriminate use of irrigation waters of different qualities
- Weathering of rocks and the salts brought down from the upstream to the plains by rivers and subsequent deposition along with alluvial materials
- Ingress of sea water along the coast
- Salt-laden sand blown by sea winds
- Lack of natural leaching due to topographical situation, especially in arid and semi-arid conditions.

Characteristics of salt affected soils

In general, saline and alkali (sodic) soils are the two major groups of salt affected soils that can be distinguished on the basis of physico-chemical and biological properties and their geographical and geochemical distribution (Szabolcs, 1979). The above mentioned two categories of salt affected soils account for a very large fraction of salt affected soils in the world-over, there are transitional and borderline formations which are likely to have intermediate properties (FAO, 1988). Saline and alkali soils are defined and diagnosed on the basis of EC and SAR determination made on soil samples and the information thus generated contributes substantially to the scientific agriculture based on USDA classification given in Table 3. In India, salt affected soils are mainly confined to the arid and semi-arid and sub humid (dry) regions and also in the coastal areas. The salt deposits are of sodium carbonate, sulphate and chloride with some calcium and magnesium. In addition to the parameters proposed by the USDA, Indian scientists considered the nature of soluble salts. Further, the pH value of 8.5 is too high, as iso-electric pH for precipitation of $CaCO_3$ at which sodification starts is 8.2 and mostly the pH is associated with the ESP of 15 or more (Abrol *et al*., 1980). The classification according to the Indian system is presented in Table 4. As there are large black soil (*Vertisol*) areas in the country, the limit of ESP for defining sodic soil can be appropriately lowered based on the study conducted. It is inferred from the study (Nayak *et al*., 2004) that at salinity of ≤ 2 dS m^{-1}, the *Vertisol* can be grouped as sodic if the ESP is > 6 and >10 in clayey and silty clayey soils, respectively. Similarly, at salinity of ≤ 4 dS m^{-1}, the *Vertisol* can be grouped as sodic if the ESP is > 13 and >21 in clayey and silty clayey soils, respectively (Table 5). Whereas at higher salinity *i.e*.,> 6 dS m^{-1} even at fairly high ESP also, the soil saturated hydraulic conductivity (Ks) and dispersion are not affected adversely. It can be fairly concluded that the coupled salinity and ESP values may be considered as the limit for sodic class and needs further attention for deciding minimum data sets for future management of saline *Vertisols* (Chinchmalatpure *et al.,* 2011).

Table 3. Classification of salt affected soils

Class	ECe, dS/m	pH(s)	ESP	Local Names
Saline	>4	<8.5	<15	Thur, Shora, Khar, Kari, Loma, Pokkati, Soulu
Saline-sodic	>4	>8.5	>15	Usar, Kallar, Karl, Chopan, Reh, Kshar, Bari
Sodic	<4	>8.5	>15	Rakkar, Bara, Usar, Karl, Chopan

Table 4. Indian system of classification

Soil Characteristics	Saline soils	Alkali soils
pH	< 8.2	> 8.2
ESP	< 15	> 15
ECe	> 4 dS/m	Variable, mostly < 4 dS/m
Nature of soluble salts	Neutral, mostly Cl^-, SO_4^{2-}, HCO_3^- may be present but CO_3^{2-} is absent.	Capable for alkaline hydrolysis, preponderance of HCO_3^- and CO_3^{2-} of Na^+

Table 5. Grouping of sodic *Vertisols*

Texture	Soil salinity		
	$\leq$2 dS m^{-1}	$\leq$4 dS m^{-1}	$\geq$6 dS m^{-1}
	<---------------------------- ESP--------------------------------->		
Clay	>6	>13	>18
Silty clay	>10	>21	>32
Overall *Vertisols*	6-13	13-20	20-32

Saline soils

These soils have electrical conductivity (EC) of the saturation extract more than 4 dS m^{-1}, the exchangeable sodium percentage (ESP) less than 15 and the pH is less than 8.5. With adequate drainage, the excessive salts present in these soils may be removed by leaching thus bringing them to normalcy. Saline soils are often recognized by the presence of white crusts of salts on the surface. The important soluble salts comprise cations *viz*., sodium, calcium and magnesium with low amounts of potassium and anions *viz*., chloride, sulphate and sometimes nitrate. Owing to the presence of excess salts and the absence of significant amounts of exchangeable sodium, saline soils generally are flocculated and as a consequence the permeability is equal to or higher than that of similar non-saline soils.

Saline-alkali soil

These soils will have EC of the saturation extract more than 4 dS m^{-1}, the ESP greater than 15 and the pH is seldom higher than 8.5. These soils form as a result of combined process of salinisation and alkalisation. As long as excess soluble salts are present, these soils exhibit the properties of saline soils. Leaching of excess soluble salts downward, the properties of these soils will become like that of non-saline alkali soils. On leaching of excess soluble salts, the soil may become strongly alkaline (pH > 8.5), the particles disperse and the soil becomes unfavourable for the movement of water and for tillage.

Non-saline alkali soil

Alkali soils which are known as Sodic or Solonetz have their ESP greater than 15, the ECe less than 4 dS m^{-1} and the pH ranges between 8.5 and 10. The exchangeable sodium content influences significantly the physical and chemical properties of these soils. As the ESP tends to increase, the soil tends to become more dispersed. Sometimes distinction is made between alkali and sodic soils especially in *Vertisols*, where the term 'sodic' is preferred as pH of these soils increases slowly with increase in ESP.

Salt affected agro ecological sub-regions

The eight agro-climatic zones identified by the Gujarat Agricultural University (NARP Status Report, GAU) have been further sub divided into Agro Ecological Sub Regions (Table 6). The coastal agro-climatic zones which are salt affected and their major characteristics are as below.

Table 6. Major characteristics of coastal salt affected soils of different agro climatic zones

Agro climatic zone	Soil type	Soil Texture	Rainfall	Principal agricultural Crops	Area (ha)	Irriga-tion %
South Gujarat heavy rainfall	Salt affected	Clay to clay loam	1200-1500	Paddy, Sugarcane, Horticultural crops	21000	52
South Gujarat	Black cotton, salt affected	Clay to clay loam	900-1000	Paddy, Cotton, Sorghum, Pulses	14000	56
Middle Gujarat	Medium black, salt affected	Clay loam to silt loam	500-700	Paddy, Pearl millet, Cotton, Castor. Tobacco and banana	26000	78
North Saurashtra	Saline Sodic	Clay	500-600	Groundnut, Sorghum, Pearlmillet, Wheat	187000	22
	Coastal alluvial	Clay loam to clayey	300-400	Groundnut, Sorghum, Pearl millet	181000	9
	Coastal alluvial	Silty clay	500-700	Groundnut, Sorghum, Pearlmillet, Chick pea	299000	22
South Saurashtra	Low lying saline sodic with saline ground water	Clay	700-750	Cotton Sorghum	50000	10
	Mixed red and black and salt affected	Sandy clay loam to clay loam	750-1000	Groundnut Sugarcane, banana, Coconut and other horti-cultural crops	96000	15
	Coastal alluvial	Sandy loam to silty clay loam	750-1000	Groundnut, sesamum, Sorghum, Pearl millet, and horticultural crops	286000	18
Kutch	Hydromorphic salt affected	Clay loam to silt loam	400-500	Cotton, Pulses, Sorghum, Cluster bean, Fruit crops	49000	8
	Highly salt affected	Clay loam to silt loam	350-400	Cotton castor		
Bhal	Sodic	Sandy loam to clay	550-650	Cotton Sorghum wheat cumin, dill seed	160000	7
	Highly saline	Sandy loam to clay	600-700	Forestry	-	-

Reclamation and management of salt affected soils

Technological knowledge generated till date has helped in taming the problem in large tracts of land in different countries to restore their full potential. However, new challenges are set to be faced either due to changing climate or land use anomalies, leading to exponential increase in the area under salinity. With new challenges cropping up, soil salinity related stresses can be more pronounced and more damaging to crop production in coming years. It is well established that plant growth can be restricted or entirely prevented by increased levels of salinity and alkalinity in the soil. The productivity of these soils can be restored by management and reclamation using different technologies available with the ICAR-Central Soil Salinity Research Institute. The processes of accumulation of salts and build-up of ESP have to be reversed. To achieve this, provision of adequate drainage, replacement of Na^+ ions from the exchange complexes and leaching out of soluble salts below root zone has to be ensured. For reclamation, different methods like physical, chemical, hydro-technical and biological are to be adopted so that yield level of the crops grown on these soils can be enhanced and in turn income of the farmers. Physical methods include deep ploughing, sub-soiling, sanding, profile inversion, scrapping etc. Hydro-technical methods include leaching of salts, provision of drainage, use of leaching curves *etc*. Under chemical methods, application of gypsum is the prominent one. Other chemical techniques include application of calcium chloride, calcite, phospho-gypsum and iron pyrites *etc*. Biological methods include green manuring, addition of FYM and other organic manures, incorporation of crop residues, press mud, municipal solid waste, microbial consortium, biosaline agriculture, use of salt tolerant varieties *etc.*

Strategies for enhancing farm productivity and farmers' income:

For increasing farmers' income, the rate of growth in farm income has to be sharply accelerated and therefore strong measures will be needed to harness all possible sources of growth in farmers' income and these sources are improvement in productivity, resource use efficiency, lowering of the cost of production, increase in cropping intensity, crop diversification with high value crops, use of salt tolerant varieties, use of proper technology, *etc*. ICAR-CSSRI has developed various technologies for reclamation and management of salt affected soils and with the use of these technologies for the purpose, the hitherto unproductive or low productive salt affected land can be put under optimum productivity which will lead to more production and income.

1. **Gypsum technology for reclamation of sodic soils**: Using this technology till date, about 1.94 Mha sodic land has been reclaimed and the reclaimed area contributes 14-15 million tonnes of food grains to the National pool. The cost of intervention and output per unit area is about Rs. 42500 per hectare. Farmers obtained 4 tonnes/hectare rice and 2 tonnes/hectare wheat yield from reclaimed alkali land right from the first year of the reclamation, which increased to 5 and 3 tonnes/hectare during 3rd year onwards, respectively with 135 man-days of employment generated per hectare per year. Its net present worth (NPW) estimated to be Rs. 52,000/ha. This technology improved soil health, increased resource use efficiency, raised farm income, reduced poverty, minimised inequity, reduce flood hazards and waterlogging and improve quality of overall environment.
2. **Sub-surface drainage technology:** Subsurface drainage is an effective technology for amelioration of waterlogged saline irrigated lands in India. The technology has been widely adopted and replicated in Haryana, Rajasthan, Gujarat, Punjab, Andhra Pradesh, Maharashtra and Karnataka and almost about 66084 ha waterlogged saline soils have been reclaimed. Due to notable increase in crop yields, the technology results in 3 fold increase in farmers' income. The technology also generates around 128 man-days additional employment per ha per annum and also enhanced the crop intensity by 40-50%, significant enhancement in crop yields (up to 45% in paddy, 111% in wheat, 215% in cotton and 138% in sugarcane in different parts of the country, and farm income by 200-300% leading to benefit cost ratio of 1.5. (Kamra and Sharma, 2015; Chinchmalatpure *et al.,* 2016 and Kaledhonkar *et al.,* 2009).
3. **Cultivation of *Salvadora persica* on highly saline land**: This species was found to grow well on saline black soils having salinity up to 55 dS m^{-1} and found to yield well. Based on the studies conducted, the National Bank for Agriculture and Rural Development (NABARD), Mumbai in association with the RRS, Bharuch has developed a bankable model scheme for

cultivation of *Salvadora persica* on salt affected black soils through the project sponsored by NABARD. Regreening of highly saline black soils that cannot be put under arable farming and reduction in salinity by 4th year onwards that enable to take up intercropping with less tolerant crops/forages. Planting of *Salvadora persica* would fetch about Rs. 7000/- per hectare (Rao *et al.,* 2004)**.** Apart from this, the species provide a dwelling place for birds and enhances the environmental greening.

4. **Cultivation of dill (*Anethum graveolens*):** Non-conventional crop like dill can be grown using residual moisture resulting in 2.6 q/ha seed yield with net returns of Rs. 8000/-. This crop forms an ideal option for the state in general and the region in particular, which *by and large* faces water scarcity problems (Rao *et al*., 2000). Under saline water irrigation, crop would yield net returns of Rs. 16500/- ha^{-1} with Rs. 6000/- per hectare as cost of cultivation. The benefit: cost ratio works out to be 2.75. This crop thus would help farmers of the region to go for the second crop in the *rabi* season on lands, which hitherto remain fallow due to water and salinity constraints. Thus dill crop can be taken up using residual moisture and/or with saline ground water. The green can be used as leafy vegetable, an additional source of income.
5. **Farmers based ground water recharge:** The ICAR-Central Soil Salinity Research Institute, Karnal along with its Regional Research Station at Bharuch, Gujarat has designed artificial groundwater recharge structures for better harnessing rainwater in Bharuch and Narmada districts mainly for cultivation purposes. The CSSRI, RRS, Bharuch has installed 15 artificial rainwater recharge wells at farmers' fields in Bharuch and Narmada districts of Gujarat through the financial assistance from the Ministry of Water Resources, Government of India. The Prolonged availability and improvement in groundwater quality in recharge well of Gujarat increased farmer's income by Rs. 30000 to 75000 per ha in banana and papaya crops (Success Story-ICAR website, 2013).
6. **Integrated farming system model for salt affected black soils:** The farming system model comprised of a rain water harvesting structure, fruit species like papaya and vegetables on dykes, other fruit crops like banana, jamun, aonla, seed spices, woody biomass species like *Eucalyptus* and *Pongamia* and a compost pit has been developed with a aim to get farmers a staggered income throughout the year. Water productivity of banana, papaya, dill, coriander, brinjal, bottle gourd and tomato has been worked out along with benefit: cost ratios. Papaya followed by banana amongst different fruit species; dill followed by ajwain and coriander amongst spices and bottle gourd followed by tomato and brinjal amongst vegetables showed higher B:C ratios. The B/C ratios of vegetables and spices were more than that of the fruit species. The productive components like fruits, vegetables and spices could provide a net income of about Rs. 52258/- ha^{-1}. In view of low water requirement, spices, vegetables and papaya are better suited for water scarce regions like Bara tract of Gujarat with saline black soils (Rao *et al.*, 2009).
7. **Cotton-pulse intercropping proved to be beneficial on moderately saline black soils:** Farmers who take cotton as rainfed mono crop in the Bara tract in Amod, Vagra and Jambusar talukas of Bharuch district of Gujarat and other parts of the state do face crop losses due to salinity and due to other climatic vagaries. Under such situations, intercropping with pulses provides some remuneration to the farmer in the event of failure of cotton crop. The farmers of the region have been adopting the cotton intercropped with pulse technology for maximising the production and income also.
8. **Cultivation of forage grasses on saline black soils:** Gujarat state has one of the largest dairy industries in the country. As the fodder produced on arable lands and grasslands is not sufficient to meet the demands of the cattle population, cultivation of forage grasses,

Dichanthium annulatum and *Leptochloa fusca* in a ridge-furrow planting system with 50 cm high ridge and 1 m between midpoints of two successive ridges was found ideal in saline black soils having salinity up to 8-10 dS m^{-1}. For maximizing forage production on saline black soils, *Dichanthium* on ridges and *Leptochloa* in furrows form ideal proposition. Cultivation of salt tolerant grasses like *Dichanthium annulatum* and *Leptochloa fusca* on moderate saline soils result in 1.9 t/ha and 3.2 t/ha, respectively (Rao *et al.,* 2011).

9. **Cultivation of *desi* cotton on saline *Vertisols*:** *Desi* cottons are known for their short staple characteristics, deep root system, resistance to diseases and pests and drought. The ICAR-CSSRI, RRS, Bharuch has been working on improvement in salt tolerance of herbaceum and arboreum cotton and has screened and identified salt tolerant germplasm of cotton. Studies conducted by the station has revealed that *desi* cotton line (G Cot 23) as salt tolerant and high yielding even at 11.2 dS m^{-1} salinity and identified as salt tolerant *desi* cotton variety. On-farm Trials were undertaken on farmers' fields in Bhal area (Rajpara village, Dholera taluka, Ahmedabad district) and Bara tract (Bojadra and Kalak villages of Jambusar taluka, Bharuch district), where G Cot 23 recorded yield of 1.8 to 1.9 t ha^{-1}. Field trials were also taken up on farmers' fields with G. Cot 23 on saline *Vertisols* in four villages namely Rajpur, Mingalpur, Shela and Kamatalav in Dhandhuka taluka of Ahmedabad district indicated seed cotton yields in the range of 1.7-1.8 t/ha and the salinity ranged from 9.4 to 10.2 dS m^{-1} (Success Story-ICAR website, 2015).
10. **Salt tolerant cultivars in field crops**: Salt tolerant cultivars (STCs) capable of growing in un-reclaimed or partially reclaimed soils represent a sustainable approach to obtain high productivity in saline soils and increase in income of farmers. This strategy assumes several greater importances in sodic areas still uncovered by the gypsum-based package and other technologies. Again, they are an attractive option for the poor farmers lacking material resources to use the costly chemicals. STCs developed in different crops (Table 7) have been adopted in many parts of Punjab, Haryana, Uttar Pradesh and other states (ICAR-CSSRI, 2015). Many promising lines such as CSR 46 in rice, KRL 283. KRL 345, KRL 347 and KRL 351 in wheat have been identified and are being evaluated for release. Several potential genetic stocks have also been developed for the use as parents in future selection and hybridization programs.

Table 7. Salt tolerant cultivars developed and released

Crop	Cultivars
Rice	CSR 10, CSR 13, CSR 23, CSR 27, CSR 30 (Basmati), CSR 36 and CSR 43
Wheat	KRL 1-4, KRL 19, KRL 210 and KRL 213
Chickpea	Karnal Chana- 1
Indian Mustard	CS 52, CS 54, CS 56 and CS 58
Dhaincha	CSD-123 and CSD 137

Conclusion:

Salt affected soils either due to excess soluble salts or due to high exchangeable sodium content have become non-productive, so to restore its productivity, it is highly essential to reclaim and manage these soils using different specific technologies. To achieve this restoration, there would be a need for the involvement of relevant stakeholders such as farmers, public institutions (research and extension institutions, other line department of government, KVK, NGO) for expansion, adoption and awareness about available technologies which not only help in restoring the productivity but also enhancing the productivity and directly or indirectly increase farmers' income.

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Doubling Farmer's Income through Selection of Crops and their Varieties for Salt Affected Soils

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Introduction

All the crop plants experience various kinds of environmental stresses during their lifetime, which leads to development of a struggle in them towards survival of the fittest. These environmental stresses are of two types: biotic stress and abiotic stress. Biotic stresses are due to living organisms like pathogens, insect pests and weeds, while abiotic stresses are caused by excess or limitation of the non-living components of the ecosystem viz., salinity, drought, heat, cold, waterlogging, nutrient deficiencies, metal toxicity, gaseous pollution and UV radiations. These abiotic stresses are major limitation to modern agriculture and causing many environmental issues. Drought and salinity are two main causes of crop losses throughout the world.

Salinity would result in up to 30 per cent land deterioration in coming 25 years and 50% up to 2050 (Wang *et al.,* 2003). It has been estimated that more than 800 million hectares of world lands are affected by both saline and sodic conditions which covers almost 6% of the total world land area. Salt affected areas are increasing in developing countries like India, Pakistan and Egypt due to scanty rainfall, high evapo-transpiration, use of saline water for irrigation and faulty practices of water use management (Arzani, 2008). It is a matter of great concern that salt affected land is increasing at rapid rate (20%) under irrigated regions than in arid on semi-arid regions (2%). Every minute, the planet is losing a minimum of 3.0 ha of cultivated area due to salinity (FAO, 2008).

Soil salinity is one of the major environmental constraints in agricultural crop production in our country. Salt affected soils occur to a tune of 6.73 M ha in India of which Gujarat accounts for 2.22 M ha (Mandal and Sharma, 2008) *i.e.*, 32 per cent of the country's total salt affected area and thus needs a holistic approach for generating economically viable agro-management strategies. In South Gujarat alone around 6.33 lakh ha area is salt affected (Table 1), which covers coastal parts of Bharuch, Surat, Navsari and Valsad districts. The coastal and inland saline soils were found to be highly saline with salinity in the Bhal area ranging from 25-70 dS m^{-1}.The ground water salinity varied from as low as 4 dS m^{-1} in rainy season to 45-60 dS m^{-1} during summer.

Table 1. Extent and distribution of salt affected soils in Gujarat

Code	Description of Agro climatic zones of Gujarat	Salt affected area (ha)
1	South Gujarat Heavy rainfall area	19845
2	South Gujarat Zone	44531
3	Middle Gujarat Zone	9080
4	North Gujarat Zone	135571
5	North West Zone	1005109
6	North Saurashtra	295247
7	South Saurashtra	117853
8	Bhal and Coastal region	296100
9	Rann of Kachchh	298661

Source: Mandal and Sharma (2008)

Production losses due to soil degradation by salinity/alkalinity

Studies conducted over past years have indicated the loss in farm production due to salt-affected soils in India by comparison of normal and salt-affected farms. Different levels of salinity decreased paddy yields by 10–80 % in Gujarat, and in Haryana farms having salinity had to forego 25 % of their lands as fallow as compared to only 4 % on farms without salinity. A recent study estimated the losses caused by salt-affected soils in India from major crops (Table 2). The cereals are the major contributor (8.3 million tonnes) to the total production losses followed by cash crops (7.13 million tonnes), oilseeds (0.87 million tonnes), and pulses (0.52 million tonnes). Among all the crops, wheat suffered the highest production loss of 4.06 million tonnes followed by sugarcane (4.02 million tonnes), rice (3 million tonnes), potato (2.25 million tonnes), and cotton (0.85 million tonnes).

Table 2: Production losses in various crops due to salinity in India

Crop	**Gross salt-affected area (ha)**	**Production loss (tonnes)**	**Production loss (%)**
Rice	23,40,920	30,06,433	17.85
Wheat	28,89,917	40,65,569	24.14
Maize	2,81,912	3,69,499	2.19
Pearl millet	11,95,271	7,72,180	4.58
Sorghum	3,20,400	42,647	0.25
Barley	33,676	43,119	0.26
Ragi	24,060	6515	0.04
Other cereals	4075	472	0
Total cereals	**70,90,231**	**83,06,435**	**49.31**
Rapeseed & mustard	6,78,600	1,97,619	1.17
Sesame	2,07,461	24,844	0.15
Groundnut	5,52,851	6,43,434	3.82
Soybean	95,023	8812	0.05
Sunflower	26,789	865	0.01
Total oilseeds	**15,60,724**	**8,75,574**	**5.2**
Bengal gram	5,37,787	2,18,362	1.3
Pigeon pea	1,19,380	61,401	0.36
Black gram	1,32,427	47,820	0.28
Green gram	2,74,038	80,564	0.48
Other pulses	2,64,934	1,16,498	0.69
Total pulses	**13,28,567**	**5,24,645**	**3.11**
Cotton	9,67,143	8,50,725	5.05
Sugarcane	2,22,903	40,27,947	23.91
Potato	4,11,090	22,58,677	13.41
Total cash crops	**16,01,136**	**71,37,349**	**42.37**
Total	**1,15,80,658**	**1,68,44,003**	**100**

Source: Sharma *et al.* (2015)

Production and monetary losses from major states was also estimated in the study (Table 3). Uttar Pradesh suffered the highest production losses of 7.69 million tonnes followed by Gujarat (4.83 million tonnes), which accounted for nearly 79% of the total production losses. These two states contributed Rs. 181.92 billion to the total monetary losses in the country. India loses 16.84 million tonnes of farm production valued at Rs. 230.19 billion annually, due to salt-affected soils from 14 states spread across 240 districts.

Table 3: State-wise production and monetary losses due to salinity

States	Gross salt-affected area (ha)	Production loss (million tonnes)	Monetary loss (Rs. million)
Haryana	4,55,568	0.719	7791
Punjab	3,01,723	0.144	975
Uttar Pradesh	25,73,242	7.695	81,291
Madhya Pradesh	2,39,271	0.032	882
Andhra Pradesh	6,26,893	0.501	7308
Karnataka	1,47,387	0.016	309
Kerala	17,131	0.004	71
Tamil Nadu	3,94,527	0.147	1378
Gujarat	41,29,376	4.832	1,00,635
Maharashtra	9,86,265	0.923	4987
Rajasthan	5,61,756	0.19	4032
Bihar	2,82,723	0.554	5594
Orissa	2,73,275	0.197	2658
West Bengal	5,91,521	0.89	12,286
Total	1,15,80,658	16.844	2,30,196

Source: Sharma *et al.* (2015)

Data presented above clearly indicates that India suffers huge losses due to problem of land degradation caused by salinity. To overcome these problems, suitable adaptation and mitigation strategies are need of the hour. Enhancing the income of the farming community living in these areas could only be possible through proper resource management and suitable technological interventions for increasing the production.

Crop production in saline soils

Salinity is a grave threat to the crop productivity worldwide due to its harmful effect on the plant growth and development. Toxic level of salts in the plant system induces many changes in metabolism such as disturbance in the water uptake and water balance, gas exchange and transpiration, photosynthesis and respiration, growth pattern, morphology and anatomy of the plants and imbalanced hormonal concentration. The negative impact of salinity on plant growth and development are due to three main phenomenon *i.e.* (1) Low water potential of root environment resulting in water shortage in the plants, (2) Toxicity due to Na^+ and Cl^- ions, and (3) Imbalance in the plant nutrition due to decreased nutrient uptake and transport to the above ground portion of the plants (Munns and Tester, 2008; Munns, 2002). Hence, it was found that salinity impaired every process of plant system and significantly reduced crop yield, productivity and quality.

Various measures have been suggested to check the spread of salt affected soils. The engineering approaches for reclamation of salt-affected soils involve the provision of adequate drainage for salt leaching out of the root zone and the use of amendments like gypsum. But due to high expenses on the amendments with low soil permeability and scarcity of good quality irrigation water, the engineering approach is applicable to limited area (Qureshi and Barrett-Lennard, 1998). Hence, bio-saline approach has gained a significant popularity as it involves various durable, economical and sustainable strategies such as introduction of salt tolerant species (*e.g.* kallar grass) and development of salt tolerant crops varieties. Salt tolerance potential varies among species (Maas, 1986) as some species are more tolerant (*e.g.,* barley, sugarbeet) and moderately tolerant (*e.g.* rye, sorghum, soybean, sunflower) and while others are found to be salt sensitive (*e.g.* okra, onion, peas, carrot).

Hylophytes (*e.g.* Atriplex) are those plant species which show no significant reduction in growth under saline conditions while glycophytes show poor performance on saline soils which can lead to death of the plant also. Within glycophytes, vast diversity is found for salt tolerance (Maas, 1986), as some species are less susceptible (barley and sugar beet), moderately salt susceptible (sorghum and soybean) whereas, some are highly salt susceptible (okra, carrot and onion). Reaction of some crops when grown under saline condition along with their tolerance reaction has been estimated by many researchers (Maas and Hoffman, 1997) and crops have been classified (Table 4) as moderately susceptible (MS), susceptible (S), moderately tolerant (MT) and tolerant (T).

Table 4. Reaction of some important crops to salinity stress

Common name	Botanical name	Tolerance based on	Threshold(EC_e) dS/m	Rating
Corn	*Zea mays*	Ear FW	1.7	MS
Cotton	*Gossypium hirsutum*	Seed	7.7	T
Peanut	*Arachis hypogaea*	Seed yield	3.2	MS
Rice	*Oryza sativa*	Grain yield	3.0	S
Sorghum	*Sorghum bicolor*	Grain yield	6.8	MT
Soybean	*Glycine max*	Seed yield	5.0	MT
Sugarcane	*Saccharum officinarum*	Shoot DW	1.7	MS
Sunflower	*Helianthus annuus*	Seed yield	4.8	MT
Wheat	*Triticum aestivum*	Grain yield	6.0	MT

Source: Maas and Hoffman (1997)

Selection of crops for saline areas

Crops differ in their ability to tolerate to salinity/alkalinity. The high-water requiring crops like sugarcane and rice should be avoided with brackish water, as these aggravate the salinity problems. Proper time of sowing also plays an important role in salt tolerance of the crop. For example, late sown crops like wheat can tolerate only lower levels of salinity than timely sown crop. Crop tolerance is also increased when crops are grown in cooler climate due to low ET demand prevailing in such conditions. In coarse textured soils, comparatively highly saline water can be used when compared to clay soils, due to lower salinity build up in root zone. Relative sensitivity of different crops to salinity is given in Table 5.

Table 5. Growth stage sensitivity of different crops to salinity

Crop	Relative sensitivity
Wheat	Presowing > Crown Root initiation > Milking > Flowering > Jointing
Maize	Silking > Tasseling > Presowing > Knee Height
Pigeon pea	Presowing > Flowering to pod development
Dill	Vegetative > Flowering > Seed formation
Mustard	Branching > Flower initiation > Pod formation
Safflower	Grain filling > Flower initiation > Branching

Over the years, experiments on various crops have been conducted at ICAR-CSSRI, Karnal and its Regional Stations. Many crop varieties have been identified and developed which has been listed (Table 6). Tolerance levels of various crops and their suitability for cultivation in the various parts of the country has been described. This list may be used as ready reference by various stakeholders including farmers for selection crops and their varieties depending on the severity of salinity in the salt affected area.

Table 6. Crops and their varieties with their salinity tolerance levels

Varieties of Crops	Stress condition (EC/pH up to which variety can be cultivated	Yield (q/ha) in salt stress condition	Recommended area/states of the country
Rice (*Kharif* season)			
CSR 23	ECe 4.0-10 dS/m pH 9.0-9.9	40	Salt affected states/coastal area of the country
CSR 27	ECe 4.0-10 dS/m pH 9.0-10.0	40	Salt affected states/coastal area of the country
CSR 36	ECe 4.0-10 dS/m pH 9.0-9.8	40	Salt affected states/coastal area of the country
CSR 36 and CSR 43	EC 4-10 dS/m	40-45	Coastal region of Gujarat
Rice (*Rabi* season)			
Canning 7	EC 6.0-8.0 dS/m	40-45	Eastern coast region
Boby	EC <6.0 dS/m	31-40	
Annada	EC 6.0-8.0 dS/m	35-45	
Bidhan 2	EC 6.0-8.0 dS/m	45-50	
CSR 4	EC 6.0-8.0 dS/m	35-40	
Lalat	EC 6.0-8.0 dS/m	22-30	
WGL 20471	EC 6.0-8.0 dS/m	40-45	
IET 7486	EC 6.0-8.0 dS/m	30-40	
Wheat			
KRL 210	ECe 4.0-6.4 dS/m pH 9.0-9.2	30-34	Salt affected states/coastal area of the country
KRL 213	ECe 4.0-6.4 dS/m pH 9.0-9.2	30-33	Salt affected states/coastal area of the country
Wheat salt tolerant varieties (KRL 19/ KRL210 and KRL 213)	EC_e 8-10 dS/m) and saline water irrigation with EC_{iw} 9-11 dS/m)	25-30	Salt affected *Vertisols* area in Bara tract of Gujarat
Oilseeds			
Mustard			
CS 52	ECe 6.0-9.0 dS/m pH 9.0-9.3	15-16	Salt affected states/coastal area of the country
CS 54	ECe 6.0-9.0 dS/m pH 9.0-9.3	16-19	Salt affected states/coastal area of the country
CS 56	ECe 6.0-9.0 dS/m pH 9.0-9.3	16-19	Salt affected states/coastal area of the country
CS 58	ECe 9.0-11.0 dS/m pH 9.0-9.4	20-22	Salt affected states/coastal area of the country
Chickpea			
Karnal Chana-1 (CSG8962)	ECe 4.0-6.0 dS/m pH 8.0-9.0	14-16	Salt affected states/coastal area of the country

Cotton			
G.COT 23 (*Desi* cotton, Herbaceum cotton)	EC_e 8-10 dS/m	18-19	Bhal, Bara tract, Saurashtra area of Gujarat. Coastal area of Bharuch, Anand and Ahmadabad districts of Gujarat
G.Cot DH 7 (Cotton)	EC_e 8-10 dS/m	17-18	Bhal, Bara tract, Saurashtra area of Gujarat
Forage grasses and other crops			
Dhaincha (sesbania)-CSD 137 and CSD-123	EC_e 7.0-7.5 ds/m pH 9.6-9.8	350-430 q/ha	Tolerance to sodicity, salinity and waterlogged sodic coditions
Salvadora persica	EC_e> 30 dS/m	18-20 q/ha seed yield by fourth year of plating	Bhal and Bara tract/coastal area of Gujarat
Forage grass- Dichanthium annualtum	EC_e 8-10 dS/m	19-20 q/ha green forage yield	Bhal and Bara tract/coastal area of Gujarat
Leptochloa fusca	ECe 10-15 dS/m	20-25 q/ha green forage yield	Bhal and Bara tract/coastal area of Gujarat

Source: Compiled from annual reports of CSSRI

Experiments on screening of crops for salinity tolerance at ICAR-CSSRI, RRS, Bharuch

Cotton

Extensive research work is being carried out at RRS, Bharuch on breeding and evaluation of *desi* cotton. Several cotton varieties have been identified (Table 7) which gave good yield under highly saline condition compared to their susceptible *Bt* check. Studies indicated that *desi* cotton (*herbaceum* and *arboreum*) performed better under saline conditions over *hirsutum* and *Bt* cotton hybrids. Breeding efforts are continued to develop high yielding and salt tolerant variety of *desi* cotton.

Table 7. List of salt tolerant cotton varieties/accessions

Variety	Species
GBav 109, GBav 120 FDK 272, DWDa 1602, PA 828, GAM 236 and RG 804	*G. arboreum*
G Cot 23, G Cot 25, V797,GShv 362/12 and GShv 385/12	*G. herbaceum*
RHH-1007, TCH-1199, RHH-1015	*G. hirsutum*

Maize

Experiments were conducted at ICAR- Central Soil Salinity Research Institute, Regional Research Station, Bharuch (Gujarat) from 2013-16 on selection of suitable maize genotypes for cultivation using saline water irrigation. More than 100 germplasm of maize, comprising both hybrids and varieties (synthetics, composites and OPVs) were collected (Table 8) from public sector institutions (ICAR-Indian Institute of Maize Research, New Delhi; Anand Agricultural University, Anand etc.) as well as private seed companies (Monsanto India Limited, Mumbai; Subham Seeds Hyderabad etc.). Two trials, namely hybrid and varietal trial were conducted separately on salt affected *Vertisols* with local *desi* variety as check. Crop was irrigated with saline water (ECiw = 3.0-3.5 dS/m) and recommended agronomical practices were followed. After three years of testing and pooled analysis of data, DKC-8101 (7742 kg/ha) emerged as the best hybrid under saline water irrigation while SS-7077 (7264 kg/ha) ranked second. For biomass, SS-7077 (1.43 t/ha) was the best hybrid followed by 900M GOLD (1.39 t/ha) which ranked fourth (6685 kg/ha) in terms of yielding ability.

Table 8. Performance of maize genotypes under saline water irrigation

S.N.	Genotype	Yield (kg/plot)	K/Na ratio in leaf tissue	Biomass (kg/plot)
1	Kesharking 919	4.46	22.62	4.55
2	SS-6066	4.65	24.81	4.37
3	SS-7077	6.77	14.41	7.76
4	Godawari-989	4.08	18.03	3.14
5	Challenge-1	6.01	14.45	4.46
6	DKC-8101	6.15	27.25	4.21
7	900-M-Gold	5.31	16.06	7.51
8	DKC-7074	2.90	20.45	4.00
9	DKC-9117	3.79	23.47	5.49
10	Prakash	3.20	16.12	3.41
11	G-6	2.03	22.41	3.55
12	GAYMH-1	4.00	18.09	3.83
13	GWL-8	2.91	17.22	1.30
14	GWL-15	3.63	8.49	2.56
15	GYS-705	1.89	20.87	1.82

(Source: CSSRI Annual Report)

High biomass and maintenance of better K^+/Na^+ ratio were found to be highly correlated with grain yield in the superior hybrids. DKC 8101 was superior in maintaining high proline and chlorophyll levels under saline water as compared to other hybrids. Public sector hybrid Prakash and PMH-4 also had good yield potential under saline water irrigation. Among varieties and composites, DMRQPM-0903 (4645 kg/ha) and G-6 (2555 kg/ha) were superior for yield and related attributes.

Wheat

Wheat genotype KRL 370 was found salt tolerant with 3.88 t/ ha grain yield at 8.5 dS/m ECe salinity level under saline water irrigation (ECiw 9-11 dS/m), in All India Coordinated Salinity/Alkalinity trial conducted at Bharuch during *rabi* 2016-17. This entry yielded 12% more as compared to salt tolerant check KRL 19 (3.47 t/ha) and is also having good grain quality. A trial comprising of 10 entries of wheat was conducted at Experimental Farm of RRS, Bharuch and KRL 345 (5.0 t/ha) and KRL 351(4.8 t/ha) were found to be superior genotypes in third year of testing.

Conclusion

Large amount of variability is present amongst different crops with respect to their behavior under salt stress. Again, large variability is present within the crop species for varying salinity level. Farmers of salt affected regions may use these genetic resources for enhancing their productivity and increasing their income.

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Soil Properties and Nutrient Availability of Saline *Vertisols* of Bara Tract under Sardar Sarovar Canal Command of Gujarat State

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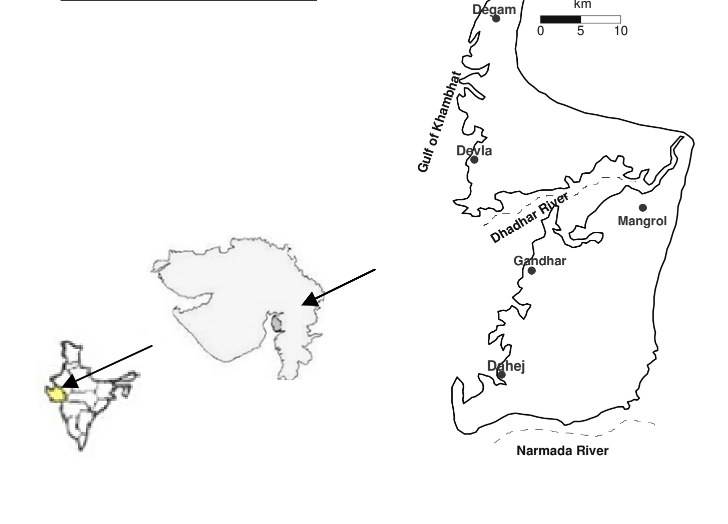
Introduction

Bara tract (Fig. 1) is spread over 111300 hectare in Vagra, Jambusar and Amod taluka of Bharuch district. Its geographical position is situated at $21^0 40'$ from $22^0 13'$ N latitude and $72^0 32'$ to $72^0 55'$ E longitude and 5-9 m above sea level. This area is bounded by the river Narmada in the South and the river Mahi in the North. The area is situated on almost flat land. About 60 per cent of the Bara tract is under cultivation, 15-20 per cent share under non-agricultural wasteland, 8-10 per cent under agricultural wasteland and the rest are under grazing. The key part of Bara tract comes under rain-based farming and some limited areas are under irrigated agriculture. Conventional agriculture is prevalent in this area due to poor economy of farmers. In such saline tract, soil productivity is low due to lack of land use planning and its management. In view of these types of problems, a study was conducted to study soil properties and to evaluate the availability of nutrients and its attributes.

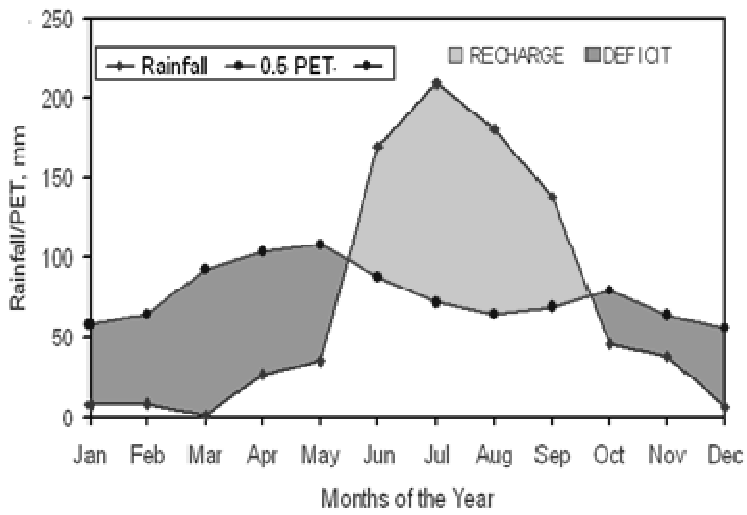
Fig. 1. Map of Bara tract



Climatic resources of Bara tract

The Bara tract falls under tropical climate. The maximum temperature in the month of May goes to 45°C and average rainfall is 737 mm. According to the analysis of rainfall data for ninety-six years (1901-1998), precipitation in the region in about 23 years had been below normal rainfall and in about 6 years was a drought condition. In Bara tract, the arrival of monsoon is irregular which affects the sowing, seed germination and seedlings stand. This region usually experienced at least one critical dry spell in the months of July-September, which is of 21-28 days. Water balance graph (Fig.2) revealed that water supply was higher than water demand (potential evapotranspiration; PET) during June to September. By rain water recharging, soil available water can be used upto month of October, while rest of nine months water supply was lower than PET.

Fig.2. Water balance diagram of Bara tract



Soil properties of Bara tract

Soils of this area have been classified in the *Vertisol* order and are also recognized as black cotton soils. The soil is deep (150 cm), fine textured (39-61% clay), having montmorillonite clay mineral, exhibited swell shrink properties and having 4-6 cm wide and 90 cm deep cracks. Black cotton soil is having the ability to hold higher amount of soil water due to high clay content but its permeability is very low and saturated hydraulic conductivity (Ks) is also very low or negligible (SSNNL, 2009; Nayak *et al.*, 2004). These soils are calcareous in nature.

In Bara tract area, it has been found that soil salinity at surface layer measuring 44,075 hectare area (40 % of Bara tract area) is having soil salinity < 2.0 dS m^{-1} *i.e.* non-saline soils. In 54871 hectare area (49%) is having soil salinity in the range of 2.0-4.0 dS m^{-1} and while 12,354 hectare area (11%) is having soil salinity more than 4.0 dS m^{-1} (Fig.3).

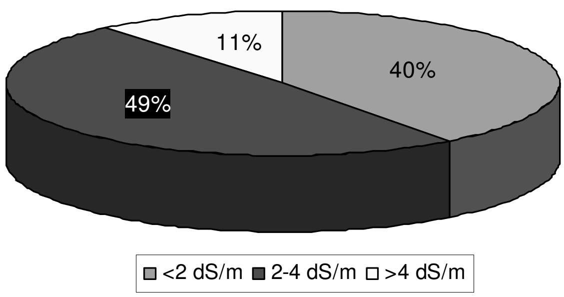


Fig. 3 Surface soils of Bara tract (%) affected by soil salinity

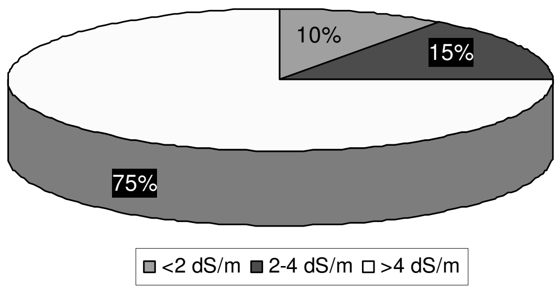


Fig. 4 Sub-surface soils of Bara tract (%) affected by soil salinity

In case of sub-surface layer, sub-surface soil salinity covering 83,475 hectare (75% of Bara tract), area is having salinity more than 4.0 dS m^{-1}. About 16695 hectare (15%) area is having soil salinity in the range of 2-4 dS m^{-1}, and in about 11130 hectare (10%) area is having < 2 dS m^{-1} soil salinity (Fig.4, Table 1).

Table 1. Extent and area (ha) of soil salinity in three talukas

Taluka	< 2 dS m^{-1} soil salinity (surface)	> 4 dS m^{-1} soil salinity (sub-surface)	> 4 dS m^{-1} soil salinity (costal salinity)	Total Area
Jambusar	20516 (18.7%)	57086 (51.9%)	32337 (29.4%)	109939 (100%)
Vagra	18466 (20.6%)	27000 (30.1%)	44324 (49.3%)	89808 (100%)
Amod	32919 (70.6%)	7694 (16.5%)	6038 (12.9%)	46651(100%)

Irrigated soils showed organic carbon content ranged from 0.30 to 0.72 per cent which is in ‘low to medium’ category while unirrigated (rainfed) soils are low in organic carbon content *i.e.* 0.22 to 0.47 per cent. The reason might be due to application of higher quantum of organic manures, apart from higher litter fall and higher quantum of roots and their subsequent deposition under irrigated conditions as a result of luxurious growth of plants (Kadu *et al.*, 2009). Higher cation exchange capacity (CEC) of these soils indicated their good potential in terms of fertility. The CEC is increasing with the depth of soil profile which might be due to presence of varying proportions of clay/ silt+clay and exchangeable Na^{2+}, Ca^{2+} and Mg^{2+} ions (Chinchmalatpure *et al*., 2008).

Major nutrient availability

In irrigated and rainfed soils, the available nitrogen was found in the range of 'low' to 'medium' (156.8 to 313.6 kg ha^{-1}) and 'low' (125.4 to 258.3 kg ha^{-1}) category, respectively. The quantities of nitrogen were found more at surface soil layer in irrigated soils and decreased with soil depth and irregular trends was found in unirrigated soils which could be the cause of churning process in black soils. The mineralization is slow in the deep soil layers due to low microbial activity, in addition to high pH, salinity or alkalinity (Paramasivan and Jawahar, 2014). Nitrogen management through inorganic or organic sources (FYM/ green manure) may be the major option for increasing crop productivity.

In irrigated and rainfed area, the respective available phosphorus was found in the range of 'high' and 'low' to 'medium', category. The variation of available phosphorus in these soils is due to soil pH, texture and organic matter. 'Low' to 'medium' status of available phosphorus in rainfed soils was possibly due to less vegetation, warm dry weather and soil constraints like calcareousness, alkalinity (Paramasivan and Jawahar, 2014) or precipitation of calcium phosphate or fixation of P by clay/ clay+silt particles (Rao *et al.*, 2008). Available potassium status in both irrigated and rainfed soils was ‘high’, which is due to presence of high quantity of micaceous (biotite and muscovite) clay minerals. The available sulphur were found in the range of ‘medium’ to ‘high’ and ‘low’ to ‘medium’ category, respectively in irrigated and rainfed soils. Higher amount of sulphur in *Vertisol* might be attributed to high SOC with heavy texture of these soils.

Available micronutrients

The status of available Fe in irrigated soils ranged from 1.9 to 6.7 mg kg^{-1} and in rainfed soils ranged from 3.3 to 3.8 mg kg^{-1} which is in the range of ‘low’ to ‘medium’ and ‘low’, respectively and its higher value in the surface layer, which may be in close relationship with the higher organic matter. In irrigated and rainfed soils, available Mn were found in the range of ‘low’ to ‘high’. Available Cu was found in the high range in irrigated as well as in rainfed soils. The available Zn in the irrigated soils was in the range of 0.22 to 0.61 mg kg^{-1} and in rainfed soils ranged from 0.19 to 0.29 mg kg^{-1} which is in the range of ‘low’ to ‘medium’. In rainfed soils, available Zn exhibited an irregular trend with soil depth, while the available Zn value was more at surface layer in irrigated soils. It has been observed that the available Fe, Mn, Cu and Zn values increased with increasing organic matter. The values of all micro-nutrients are higher in irrigated soils than in rainfed soils, which might be due to high organic sources, plant debris or root and crop management practices. However, the magnitude of available micronutrients in both the cases generally decreased with depth.

Dynamics of nutrients

In irrigated soils, NH_4^+, NO_3^-, TN, water soluble K (WSK) and exchangeable K (Exch. K) varied from 24.5 to 70.0 ppm, 35.2 to 93.8 ppm, 0.021 to 0.075 percent, 4.2 to 68.5 ppm and 162.8 to 415.6 ppm, respectively and the corresponding values for rainfed soils were 21.0 to 56.3 ppm, 7.0 to 77.0 ppm, 0.018 to 0.35 percent, 8.9 to 18.8 ppm and 266.1 to 375.4 ppm, respectively. The content of ammonical and nitrate was high in surface soils and the magnitude slightly decreased with depth showing somewhat irregular trend which might be due to churning processes of vertic clay soils and swell-shrink characteristics.

Crop productivity

Soil properties of black cotton soils of Bara tract such as soil texture, depth, cation exchange capacity, organic carbon, pH *etc*. do not vary too much, but due to wide variation in soil salinity and availability of soil moisture content, soil site suitability for cotton and wheat crop is affected. Availability of water through canal irrigation can boost productivity of existing crops in Bara tract and productivity of cotton, pearl millet and sorghum, wheat and castor might be enhanced provided scientific utilization of canal water is followed.

Conclusion:

Based on the overall results and soil-crop related constraints, following suggestions have been made for improvement/ sustaining yield of crop and soil health.

- Low status of available N and Zn in these soils necessitates use of more organic manures like farm waste / compost/ bio-compost/ vermicompost *etc*. for enhancing the fertility of soils. In specific cases, to overcome Zn deficiency, application of Zn in soil or through foliar spray and in case of N-deficiency, adoption of INM / RDF with inorganic-N in splits and incorporation of leguminous crop in crop rotation and i*n-situ* incorporation of decomposable crop residue would improve soil OC and available N status.
- Adoption of sodicity / salinity tolerant crop varieties of arable crops would be highly remunerative in soils having high soil pH, ESP above threshold limit (9.0) and moderately to highly saline soils.
- As the study area is having semiarid climate, rainwater harvesting and recycling, making field bunds for maximum rain water storage in profiles would be highly beneficial. As the ground water is saline and unsafe for irrigation in the entire tract, ground water must be used judiciously (as life-saving/ supplementary) only by mixing with rain water/ canal water or alternately with canal/ rain water to sustain crop yield and to avoid further deterioration in soil health.

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Increasing Farm Productivity and Doubling Farmers' Income

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Introduction

Hon'ble Prime Minister of India, Shri Narendra Modi has called for doubling farmers' income by 2022. The proposed strategy to double farmer's income may be

1) Big focus on irrigation with large budgets with the aim of "per drop, more crop" ; 2) provision of quality seeds and nutrients based on soil health of each field (soil health card, neem coated urea, promotion of traditional farming practices etc.; 3) large investments in warehousing and cold chains to prevent post-harvest crop losses; 4) promotion of value addition through food processing; 5) introduction of new crop insurance scheme to mitigate risks at affordable cost and 6) promotion of ancillary activities like poultry, goatary, beekeeping and fisheries.

Panning and strategizing for doubling farmers' income through three options: (1) Increasing the gross income, (2) Reducing the costs, and (3) Stabilizing prices.

1. Enhancing farmers income: a) Production growth, b) higher prices and c) diversify farm/non-farm earnings (product: higher value crops; process: precision farming; time of operation: delinking from seasonality)
2. Reduce costs: a) reduce purchased inputs; b) exploit complementarities
3. Stabilize income: a) coping mechanisms; b) insurance; c) expand irrigation cover

Projected contributions of different components to the income increase are as follows:

a. Reduction in input cost (15%)
b. Increase in productivity (30%)
c. Increase in area under cultivation (14%)
d. Agricultural diversification (20%)
e. Reduction in post-harvest loss (6%)
f. Remunerative prices (15%)

As can be seen, only two components of increase in productivity and increase in agricultural diversification constitute 50% of contributions to increased income highlighting their significance to increasing farmers' income.

Major contributors for increasing farm productivity

I. Integrated nutrient management (INM)

- **Soil test based nutrient management**

  Soil health card: Scheme was launched by the Government of India in February 2015. Under the scheme, the government plans to issue soil health cards to farmers which will carry crop-wise recommendations of nutrients and fertilisers required for the individual farm to help farmers to improve productivity through judicious use of inputs. Soil samples are to be tested in the soil testing labs across the country. Thereafter the experts will analyse the strength and weaknesses (micro-nutrients deficiency) of the soil and suggest measures to deal with it. The result and suggestion will be displayed in the card.

Use of bio-fertilizers and growth promotors

- ***Rhizobium***

  The effectiveness of symbiotic N_2 fixing bacteria *viz*. Rhizobia for legume crops has been well recognized. These rhizobia have a N_2-fixing capability up to 450 kg N/ha depending on host plant species and bacterial strains. Carrier based inoculants can be coated on seeds for the introduction of bacterial strains into soil.

- ***Azatobactor/Azospirillum*:**

  N_2 fixing free-living bacteria can fix atmospheric nitrogen in cereal crops without any symbiosis. Such free living bacterias are: *Azotobacter sp.* for different cereal crops; *Acetobacter diazotrophicus* for sugarcane. They can fix 15-20 kg/ha nitrogen per year. The crop yield can increase from 5-30%. Inoculum of Azotobacter and Azospirillum can be produced and applied as seed coating. It can also be directly utilized in field applications.

- **PSB (Phosphorus solubilising bacteria)**

  Phosphorus is the vital nutrient next to nitrogen for plants and microorganisms. The phosphorus solubilising microorganism mainly bacteria make available the insoluble phosphorus to the plants. It can increase crop yield up to 200-500 kg/ha and thus 30 to 50 kg Super Phosphate can be saved. At present PSB is most widely used biofertilizer in India. PSB can reduce the P requirement of crop up to 25%.

- **KMB (Potash mobilizing bacteria)**

  It solubilises the potash locked up in the soil into a simpler form and makes it available directly to the plants which increase the availability of potassium in the soil and thereby promote photosynthesis.

- **Mycorrhiza**

  Root-colonizing mycorrhiza fungi increase tolerance of heavy metal contamination and drought. Mycorrhizal fungi improve soil quality also by having a direct influence on soil aggregation and therefore aeration and water dynamics. An interesting potential of this fungi is its ability to allow plant access to nutrient sources which are generally unavailable to the host plants and thus plants may be able to use insoluble sources of P when inoculated with mycorrhizal fungi but not in the absence of inoculation.

- **Banana pseudo stem sap**

  Banana pseudo stem sap is rich in nutrients and having growth promoting substances. Its judicious utilization in crop production enhances crop yield with very less input costs.

- **Neem coated urea:** It has been scientifically established that Neem oil serves as an effective inhibitor if coated on Urea. Neem coating leads to more gradual release of urea, helping plants gain more nutrients and resulting in higher yields. It lowers underground water contamination due to leaching of urea. Urea is an inexpensive form of nitrogen fertilizer with an NPK (nitrogen-phosphorus-potassium) ratio of 46-0-0. On an average, 20 per cent less neem-coated urea is required as compared to ordinary urea. It is also helpful in preventing insect attacks. Urea is an important supplier of nitrogen, which is necessary for the development of plants

- **Crop rotation:** It is the suitable arrangement of successive crops in such a way that the different crops draw nutrients in different proportions or from different strata. For instance, if legumes (pulses, gram, etc.) or certain oilseeds are sown just before the cereals, they fix the atmospheric nitrogen in soil, which can be absorbed by the cereals.

II. Integrated pest and disease management (IPDM)

IPM components

- **Cultural practices**

  Cultural methods of pest control consist of regular farm operations in such a way which either destroy the pests or prevent them from causing economic loss. The various cultural practices have been grouped as under.

  - Preparation of nurseries or main fields free from pest infestation by removing plant debris, trimming of bunds, treating of soil and deep summer ploughing which kills various stages of pests. Proper drainage system in field is to be adopted.
  - Testing of soil for nutrients deficiencies on the basis of which fertilizers should be applied.
  - Selection of clean and certified seeds and treating seeds with fungicide or biopesticides before sowing for seed borne disease control.
  - Selection of seeds of relatively pest resistant/tolerant varieties which play a significant role in pest suppression.
  - Adjustment of time of sowing and harvesting to escape peak season of pest attack.
  - Rotation of crops with non-host crops. It helps in reduction of incidence of soil borne diseases.
  - Proper plant spacing which makes plants healthier and less susceptible to pests.
  - Optimum use of fertilizer. Use of FYM and biofertilizers should be encouraged.
  - Proper water management (alternate wetting and drying to avoid water stagnation) as the high moisture in soil for prolonged period is conducive for development of pests especially soil borne diseases.
  - Proper weed management. It is well known fact that most of weeds besides competing with crop for micronutrients also harbour many pests.
  - Setting up yellow pan sticky traps for white flies and aphids at far above canopy height.
  - Root dip or seedling treatment in pest infested area.
  - Inter-cropping or multiple cropping wherever possible. All the crops are not preferred by each pest species and certain crops act as repellents, thus keeping the pest species away from preferred crops resulting in reduction of pest incidence.
  - Harvesting as close as to ground level. This is because certain developmental stages of insect pests/diseases remain on the plant parts which act as primary inoculums for the next crop season. Hence, harvesting crops at ground level will lessen the incidence of pests in next season.
  - While pruning fruit trees remove crowded/dead/broken/diseased branches and destroy them. Do not pile them in the orchards which may act as source of pest infestation.
  - Large pruning wounds should be covered with Bordeaux paste/paint to protect the plants from pest/disease attack.
  - Keeping bee hives or placing flower bouquets of pollinizer cultivars facilitate better pollination and subsequent fruit set

- **Mechanical control**

  - Removal and destruction of egg masses, larvae, pupae and adults of insect pests and disease parts of plants wherever possible.

- Installation of bamboo cage cum bird perches in the field and placing parasitized egg masses inside them for conservation of natural enemies and withholding of pest species wherever possible.
- Use of light traps and destruction of trapped insects.
- Use of rope for dislodging leaf feeding larvae *e.g.* caseworm and leaf folders.
- Installation of bird scarer in the field where required.
- Installation of bird perches in the field for allowing birds to sit and feed on insects and their immature stages *viz*., eggs, larvae and pupae.
- Use of pheromones for mating disruption, monitoring pest levels and mass trapping.

➢ **Genetic practices**

- Selection of comparatively pest resistant/tolerant varieties with reasonable yield levels

➢ **Biological control**

- Biological control of insect pests and diseases through biological means is most important component of IPM. In broader sense, biocontrol is use of living organisms to manage crop damaging living organisms (pests).

Some of the common biocontrol agents are

- Parasitoids: These are the organisms which lay eggs in or on the bodies of their hosts and complete their life cycles on host bodies. As a result of this, the hosts die. A parasitoid may be of different type depending on the host developmental stage in or on which it completes its life cycle. For example, egg, larval, pupal, adult, egg-larval and larval pupal parasitoids. Examples are different species of *Trichogramma*, *Apanteles*, *Bracon*, *Chelonus*, *Brachemeria*, *Pseudogonotopus etc*.
- Predators: These are free living organisms which prey upon other organisms for their food. Examples are different species of spiders, dragon flies, damsel flies, lady bird beetles, *Chrysopa* species, birds *etc.*
- Pathogens: These are micro-organisms which infest and cause diseases in their hosts as a result of which hosts are killed. Major groups of pathogens are fungi, viruses and bacteria. Some nematodes also cause diseases in some insect pests. Important examples of fungi: different species of *Hirsutella, Beauveria, Nomurae and Metarhizium.*
- Among viruses, most important examples are of nuclear polyhedrosis virus (NPV) and granulosis viruses.
- Among bacteria, *Bacillus thuringiensis* (*Bt*.) and *B. popillae* are very common examples.

➢ **Chemical control**

- Use of chemical pesticides is the last resort when all other methods fail to keep the pest population below economic loss. Use of pesticides should be need based, judicious, based on pest surveillance and economic threshold level (ETL). This helps to minimise not only the cost involved, but also to reduce associated problems. While going for chemical control, we must understand thoroughly what to spray, when to spray, where to spray and how to spray, keeping in mind the following points.
- ETL and pest defender ratio must be observed
- Adjustment of time of sowing and harvesting to avoid the peak season of pest attack.
- If pesticides are used, only recommended dose and concentration is to be used.
- Relatively safer pesticides should be selected *e.g.* neem based and biopesticides.

- If pest is present in strips or isolated patches, whole field should not be sprayed. As far as possible strip or spot application of pesticides is to be carried out.
- Relevance of IPM practices is more important in vegetable and fruit crops because of their unique mode of consumption by human being. Pesticides which are generally highly toxic and are known to have toxic residual effects should not be recommended off hand. To get more profit, farmers do not wait until waiting periods of pesticides and harvest the crop to market the same. This leads to pesticides poisoning, chronic effects, in some cases even deaths. Thus, we have to be more careful and cautious in applying pest control practices in field crops.

III. Crop diversification

- ✓ Diversification of food grain to Pulses and Horticulture is recommended. Crop diversification refers to the addition of new crops or cropping systems to agricultural production on a particular farm taking into account the different returns from value-added crops with complementary marketing opportunities. Crop diversification that explain the positive association with crop productivity, crop income, food security and nutrition include its ability to; improve soil fertility, suppress diseases and pests (by increasing natural enemies of pests and breaking disease cycles), suppress weeds and volunteer crops.

IV. Integration of different farm enterprises

- ✓ Crop production + Horticulture crops + Animal Husbandry (Cattle, Goat and poultry)

Livestock production plays a major role in the life of farmers. It provides food, income, employment and many other contributions to rural development. Livestock farming is the rearing of animals for food and for other human uses. The word 'Livestock' applies primarily to cattle or dairy cows, chickens, goats.

V. Farm mechanisation: Use of tractors, tillers, threshers, etc. can save critical time between raising two crops, thus enabling the sowing of more than one crop.

VI. Value addition and processing

- ✓ Tomato ketch up
- ✓ Banana wafer
- ✓ Mango pickles

VII. Market led activities

- ✓ Selling of Agriculture produce by grading and attractive packing’s
- ✓ Community marketing of vegetables

Characteristics and Drainage Interventions for Management of *Vertisols*

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Introduction

Vertisols are clay-rich soils that shrink and swell with changes in moisture content. During dry periods, the soil volume shrinks, and deep wide cracks form. The soil volume then expands as it gets wetted. This shrink/swell action creates serious engineering problems. In India, *Vertisols* and associated soils are found to occur in nearly four agro-climatic conditions of India *i.e* arid, semi-arid, dry sub-humid and moist sub-humid conditions. About 76.4 M ha of *Vertisols* occur in India which is 23.2% of the total geographical area of the country (Murthy *et al.*, 1982; Table 1). These soils are predominant in Maharashtra (29.9 M ha), Madhya Pradesh (16.7 M ha), Gujarat (8.2 M ha), Andhra Pradesh (7.2 M ha), Karnataka (6.9 M ha), Rajasthan (2.3 M ha) and Tamil Nadu (3.2 M ha). Of these, salt affected *Vertisols* measuring 0.54 M ha in Maharashtra, 0.12 M ha in Gujarat state and 0.034 M ha in Madhya Pradesh. Due to their high clay content, the physical properties of *Vertisols* are greatly influenced by moisture content; usually, these soils are too sticky and unworkable when wet, and very hard when dry. *Vertisols* are potentially a highly productive group of soils. The major factor contributing to the productivity of *Vertisols* in semi-arid environments is their high water-holding capacity; in areas of uncertain and variable rainfall, sometimes too much and often too little, the ability of a soil to store sufficient water to carry crops through droughty periods is of great importance. However, some characteristics of these soils do pose some problems for the cultivation of crops and some of the problems assume greater importance where the farmer has only small holdings and limited resources. The development of salinity and sodicity in black soils region is generally associated with poor drainage, waterlogging, injudicious use of irrigation water and continuous cropping with high water demanding crops. One effective way to reduce waterlogging and salinity problems is the land drainage. An understanding of the hydraulic properties of heavy clay soils is obviously of importance in assessing their potential for reclamation since the lack of flow of water through them is a constraint preventing reclamation (Abrol, *et al*, 1988). Nijland *et al*. (2005) clarified that the one effective way to reduce waterlogging and salinity problems is drainage and the objective of any form of land drainage is to control the position of the water table. Tuohy *et al*. (2015) mentioned that the mole drain is the also effective drainage method in Irish *Vertisols*.

Table 1. Distribution of *Vertisols* in India

Sr. No	State	Area (M ha)	Per cent of total black soil area of the country	Per cent of total geographical area of country
1	Maharashtra	29.9	39.1	9.1
2	Madhya Pradesh	16.7	22.0	5.0
3	Gujarat	8.2	10.7	2.5
4	Andhra Pradesh	7.2	9.4	2.2
5	Karnataka	6.9	9.0	2.1
6	Tamil Nadu	3.2	4.2	1.0
7	Rajasthan	2.3	3.0	0.7
8	Orissa	1.3	1.7	0.4
9	Bihar	0.7	0.9	0.2
Total		**76.4**	**100.0**	**23.2**

Characteristics of *Vertisols*

Morphological characteristics

The morphological characteristics comprise the expression, shape and orientation of the structural aggregates, depth and width of cracks developing on drying. The structural arrangement together with the wide cracks is probably the most striking morphological feature of *Vertisols*. In most cases the surface horizons exhibit large, well developed angular blocky or prismatic structures, while in the sub-soil wedge shaped structural elements of all sizes do occur. Important morphological characteristics such as soil colour, texture, element composition *etc*. are all uniform throughout the solumn. A calcic horizon or a concentration of soft powdery lime may be present in or below the vertic horizon. *Vertisols* differ in surface characteristics and these strongly influence their reaction to soil tillage operations.

Physical properties

With regard to drainage the physical properties like soil texture, soil structure and consistency, pore space and porosity, infiltration and permeability (hydraulic conductivity) and water content and soil moisture storage are considered to have major importance to clay soils The basic property of *Vertisols* that endows them with a high moisture-holding capacity is their clay content, which commonly lies between 40 to 60%. Soil structure in *Vertisols* is markedly affected by the wetting and drying cycles. The depth at which the different structural elements are expressed is also a function of the moisture conditions in the different parts of the profile. The surface structure of *Vertisols* may often consist of medium to fine granular aggregates forming a loose mulch of 2-10 cm thick (self-mulching). *Vertisols* tend to have distinctive structural elements in the major body of the soil in the form of sphenoidal blocky structures with smoothed surfaces of slickenside's reflecting seasonal expansion and contraction. Soil consistency has considerable influence on the ease of soil tillage (workability) and for clay soils depends largely on the soil moisture content of the soil. *Vertisols* are known for their extreme hardness when dry but can be friable when moist or sticky and plastic when wet. Timing of tillage operations are therefore important while a proper understanding of the extent of adhesiveness of clay soils will be useful to improve upon the efficiency of ploughing implements.

Dry *Vertisols* have a very hard consistence; wet *Vertisols* are (very) plastic and sticky. It is generally true that *Vertisols* are friable only over a narrow moisture range but their physical properties are greatly influenced by soluble salts and/or adsorbed sodium. Apart from the solid mineral fraction, organic matter and water; voids are another component of the soil volume. Voids include all space in the soil and relate to the arrangement of the primary constitutes rooting patterns, burrowing of animals or any other soil forming processes such as cracking, translocation leaching etc. There is large variety in the shape, size and origin of voids but emphasis is placed on the continuous and elongated voids which are of particular importance in drainage (also known as macropores). The porosity is indication of the total volume of voids of all sizes. In non–swelling soils, porosity usually ranges from 30-60%. In swelling soils it is related to the moisture content of the soil as swelling will have a strong effect on the voids. The other physical property of *Vertisols* is hydraulic conductivity which varies among different groups, salt content and bulk density. Infiltration of water in dry *Vertisols* with surface mulch or fine tilth is initially rapid. However, once the surface soil is thoroughly wetted and cracks have closed, the rate of water infiltration becomes almost nil. If, at this stage, the rains continue (or irrigation is prolonged), *Vertisols* flood readily. *Vertisols*, by and large, are soils with good water holding properties. However, a large proportion of all water held between the basic crystal units; is not available to plants. When these soils are irrigated, the high seepage leads to a shallow water table build-up causing secondary salinisation or sodiumisation. Although the *Vertisols* have very high potential productivity with favorable climatic conditions still these soils remain underutilized owing to number of management problems *viz*., low water infiltration rate, narrow workable moisture rage, poor soil tilth and characteristically poor internal drainage. The hydraulic conductively of the *Vertisols* is generally very low (Table 2). Due to vertical heterogeneity in the root zone, the hydraulic conductivity displays appreciable reduction with increased soil depth such that, in many cases, the soil profile becomes virtually impermeable at a depth of 1m or more (Kauraw and Gupta, 1985). Such conditions become ideal for development of perched water table following rains. This leads to excessive soil moisture content in the root zone unless appropriate provision is made for drainage.

Table 2. Hydraulic conductivity (terminal infiltration rate) of some *Vertisols*

Location	**Infiltration rate, mm hr^{-1}**
Indore (M.P)	12.6
Jabalpur (M.P)	4.7
Hyderabad (A.P)	0.2
Rahuri (Maharashtra)	6.4
Satna, Patera (M.P)	4.0
Pabhani series (Maharashtra)	7.0
Sundra series (M.P)	5.0

Source: Gupta and Ranade (1988); Gupta and Verma (1983); Gupta *et al.* (1979) and Gupta *et al*. (1994)

In black soils, the ESP beyond 10 leads to structural degradation (Gupta and Verma, 1983) due to high degree of clay dispersion (Table 3). The dispersed clay clogs the pores and induces increased water retention at all suctions (Sharma *et al*., 1998). With higher water retention and increasing moisture content (Table 4) deep cracks do not develop in sodic *Vertisols* (Sharma, 1990; Verma and Sharma, 1998). The crops grown on sodic black clay soils suffer mainly on account of poor aeration of the root zone, reduced moisture availability, crusting on drying, hindrance in infiltration of irrigation water, poor nutrient availability.

Table 3. Physico-chemical properties of Sodic *Vertisols* (Indore) at ESP levels

ESP	**pH**	**EC_2 (dSm^{-1})**	**Water dispersible clay,%**	**Bulk density at 15 cm (Mg m^{-3})**	**Infiltration rate (mm hr^{-1})**
6.2	7.9	0.8	16.3	1.62	12.6
10.0	8.1	1.4	26.3	1.58	5.7
15.6	8.1	1.8	34.3	1.64	1.5
21.8	8.2	3.1	38.3	1.60	0.5
37.5	8.3	6.4	40.3	1.63	0.0
58.0	9.3	11.6	42.3	1.68	0.0

Table 4. Influence of alkalinity on cracking behaviour of black soils

Soil ESP	**Depth of crack, cm**	**Width of crack, cm**	**No. of flakes/m^{-2}**
6	>90	5-6	-
10	50	2-3	2-5
15	30	1-2	5-10
22	10	0.5-1.0	10-30
38	<2	0.2-0.3	30-50
58	0.1-0.2	0.05-0.10	80-100
>60	Negligible	Absent	Nil

Chemical characteristics

Most *Vertisols* have a high cation exchange capacity (CEC) and a high base saturation percentage. Dominant cations are Ca^{2+} and Mg^{2+} while Na^{+} plays an important role. The pH values are in the range of 6.0 to 8.0. Higher pH values (8.0-9.5) are seen in *Vertisols* with much ESP. Salinity in *Vertisols* may be inherited from the parent materials or may be caused by over-irrigation. In coastal regions *Vertisols* with high soluble salts and/or with low sulphates are seen. Leaching of excess salts is hardly possible. It is possible to flush salts that have precipitated on the wall of cracks. Chemical amelioration of the plough layer soil has only little effect on sub-soil sodicity, which restricts deep percolation. It has often been observed that after incorporation of chemical amendments, improvement in the physico-chemical properties is limited to the depth of mixing of the amendment. The untreated layer creates obstruction to percolating water. This is not only acts as an impediment to root growth but also causes development of perched water table following rain or irrigation, thereby reducing seedling emergence and inducement of aeration stress in the root zone. Even the ameliorated plough layer lacks adequate aeration because of high clay content and residual sodicity. Thus, under semi-arid climatic conditions the upland *kharif* crops grown on such soils suffer on account of poor aeration, particularly during heavy and incessant rain. The adverse effects on crop growth in such soil can be considerably mitigated by providing economically viable means of drainage.

Relation between salinity and sodicity in *Vertisols*

Studies conducted at ICAR-CSSRI, RRS, Bharuch to understand the effect of electrolyte concentration and SAR and/or ESP on flocculation and hydraulic conductivity (Ks) indicated that the ESP of soils increased with electrolyte concentration and SAR. The data also indicated that with increase in the ESP of soil, the critical coagulation concentration increases. An electrolyte concentration of 20 meq l^{-1} is necessary to cause flocculation of clayey soil at ESP of 6 and silty clayey soil at ESP of 10, beyond which, these soils undergo structural degradation. It is inferred from the study that at salinity of $\leq$ 2 dS m^{-1}, the *Vertisols* can be grouped as sodic if the ESP is > 6 and >10 in clayey and silty clayey soils, respectively. Similarly, at salinity of $\leq$ 4 dS m^{-1}, the *Vertisol* can be grouped as sodic if the ESP is > 13 and >21 in clayey and silty clayey soils, respectively. At higher salinity *ie.*, > 6 dS m^{-1} even at fairly high ESP also, the soil Ks and dispersion are not affected adversely. It can be fairly concluded that the coupled salinity and ESP values be considered as the limit for sodicity classification**.**

Main production constraints in *Vertisols*

Vertisols have a considerable potential for agricultural production but special management practices (tillage and water management) are required to secure sustained production. *Vertisols* are base rich soils and are capable of sustaining continuous cropping. They do not necessarily require a rest period for recovery because the pedoturbation brings subsoil to the surface. However, the overall productivity normally remains low, especially where no irrigation water is available. *Vertisols* are difficult to work - they are of very hard consistence when dry and very plastic and sticky when wet. Thus the workability of the soil is often limited to very short periods of optimal water status. *Vertisols* are imperfectly to poorly drained and leaching of soluble weathering products is limited. This is due to very low hydraulic conductivity of a *Vertisol i.e.,* once the soil has reached its field capacity, practically no water movement occurs. Flooding can be a major problem in areas with higher rainfall. Nitrogen is normally deficient as well as phosphorus. Phosphate fixation (as tricalcium phosphate) may occur but is not a major problem. Potassium contents are variable. Secondary elements and micronutrients are often deficient. Saline and sodic *Vertisols* may develop under irrigation, but they are rare under natural conditions.

The production constraints that prevail in *Vertisols* include:

- Much reduced permeability in swollen state so that both infiltration and internal drainage are very low,
- Poor aeration of wet soils and related root development,
- Narrow optimum moisture range for tillage and seeding operations,
- Germination and difficulties associated with rapid drying of granular surfaces and scaling and crusting,
- Salinity hazards associated with rising groundwater table and use of poor quality irrigation water, and
- Salinity and waterlogging development due to irrigation under canal command areas

Drainage intervention in salt affected and waterlogged *Vertisols*

Various technologies of surface and subsurface drainage to manage acceptable water regime and salt concentration in accordance to cropping pattern suitable for the region have been successfully experimented in different countries world over and accordingly design criteria have been established for the given region. Subsurface drainage has been widely adopted as an effective, quick and sustainable technology for water table and salinity control worldwide. Where as in most countries horizontal pipe drainage has been used, in Europe mole drainage has also been practiced successfully.

Subsurface drainage

Management of such soils involves basically the lowering of water table below root zone and leaching of excess salts. Leaching is essentially the displacement of saline soil solution with good quality water or with water of lower salt concentration. The salts displaced during leaching need to be removed by subsurface horizontal drainage system if the natural drainage of soil is impaired. Subsurface drainage has proved successful in the rehabilitation and conservation of irrigated lands in arid and semi-arid regions (Rao *et al.,* 1986). In India till date about 66084 ha area has been reclaimed using SSD. Out of 66084 ha, 26500 ha area is in Karnataka, 6500 ha area is in Maharashtra, 1300 ha area in Gujarat and 950 ha in Madhya Pradesh and 500 ha area in AP and Telgana. To go for drainage installation, a drainage planning is very much essential.

The preparation of plan

Drainage planning involves the preparation of a plan for solution to a drainage problem. The plan will generally consist of a number of measures to be taken and/or works to be constructed. In some cases the best solution to a drainage problem may well be a change in crop rotation, land use or farm practices and/or making the agricultural use of the land, which may be less susceptible to excess water. In most cases, however, the core of a drainage plan remains to construct some new drainage works suited to soil, climate, irrigation and geo-hydrological conditions and cropping pattern as the problem generally gets attention, when it is unmanageable by preventive methods. One should proceed as follows in deciding a drainage plan (Smedema and Rycroft, 1988).

1. Identification stage: The problem is identified mostly on the basis of available information with hardly any analysis or appraisal.
2. Reconnaissance/ Pre-feasibility stage: Information collected through reconnaissance type field investigations, preliminary diagnosis of the drainage problem, rough outline of possible solutions, delineation of the project area and its sub-divisions and evidence that the proposed project is promising and desirable.

3. Feasibility stage: Information collected through semi-detailed type of field investigations (mapping scale 1:10,000/50,000), presentation of the proposed plan in sufficient detail to demonstrate technical soundness and to enable cost estimation within ~10% accuracy. At this stage, information on hydraulic conductivity, drainable porosity, infiltration characteristics, soil salinity, depth of impermeable layer, aquifer parameters, groundwater fluctuation and quality, fresh water supplies, surface drainage network and the availability of outlets etc. is collected, which is a prerequisite for planning the drainage of waterlogged saline soils. In addition, knowledge on the drainage requirement of different crops and criterion for the drainage design is also required.
4. Final stage: Analysis of information collected through detailed investigations, elaboration of all plans to the extent that they can work as working documents. These include detailed plan and design, construction drawings and specifications.

Based on the research findings (Gupta, 2002) the following drain depth/spacing combinations are recommended (Table 5, 6 and 7).

Table 5. Guidelines on drain depth

Outlet conditions	Depth of the drains (m)	Optimum depth (m)
Gravity	0.9-1.2	1.1
Pumped	1.2-1.8	1.5

Table 6. Guidelines on drainage coefficient for subsurface drainage

Climatic Conditions	Range (mm day^{-1})	Optimum value (mm)
Arid	1-2	1
Semi-arid	1-3	2
Sub-humid	2-5	3

Table 7. Guidelines on lateral drain spacing

Soil texture	Spacing of drains (m)
Light textured	100-150
Medium textured	50-100
Heavy textured including *Vertisols*	30-50

Basic guidelines for Indian subsurface drainage design

Although Drainage manual (1978) and Drainage design factors (1986) have recommended general guidelines or installation procedure and drainage design parameters for more effective performance, yet on the basis of pilot studies undertaken in the past 50 years in India, few more guidelines have emerged which are mentioned below.

1. Before undertaking any drainage project into a problematic area, the primary data (technical, socioeconomic, geo-hydrological climate) and secondary (water quality) have to be collected, which are relevant to the particular area.
2. In past, cement concrete pipes were very popular in alkaline and saline areas because these pipes have not given any complaints up to 20 years in alkaline areas and 8 years in saline zones after installation. But nowadays PVC pipes are more popular than others due to its portability and light in weight.
3. Drainage depth is an issue of increase or decrease in cost of installation and also availability of machineries and labour. But it is depending on position of groundwater table, soil type and

hydraulic characteristics. For agricultural drainage, recommended depth of the lateral is 1.2 m because agricultural activities may damage the laterals.

4. Drain spacing is classified on the basis of the texture of the soil. The lateral spacing, size and grade (in %) for light-textured soils are ranging between 100 and 150 m, 100 mm and 0.10 %, respectively, 50 and 100 m, 125 mm and 0.075 % for medium-textured soil and 30 and 50 m, 150 mm and 0.05 % for heavy textured soils.
5. On the basis of climatic conditions, drainage coefficient has an optimum value which lies between 1 and 3 mm/day (i.e., arid region is a 1 mm/day, semiarid region is a 2 mm/day, and subhumid region is 3 mm/day).
6. Continuous movement of water in the pipe and aquifer system collects sediment in the pipes which may affect the performance of the drainage system. For resolving the problem, the provision of filters and envelopes on the drain pipes has to be adopted. Filter/envelope material is used to filter that surrounds drain pipe, and these are commonly used along with drain pipes (geotextile, polypropylene, coconut fiber, polystyrene and foam plastic). The traditional filter material is a combination of gravel and coarse sand.
7. Normally the drain effluent is disposed in the canal, salt-making ponds, fishpond, or it can be reused in crop production. The several methods have been suggested by researchers for effluent reuse in irrigation such as blending and mixing.

Subsurface drainage in *Vertisols*

As per documentary evidences, subsurface drainage has been experimented in India for the last 130 years or so. The first-ever subsurface drainage experiment to reclaim salt affected land was conducted by Mr. Robertson in 1873 (Gupta, 2002 and Gupta, 2003). Similarly, Manjari drainage scheme in Maharashtra state is located in Khadakwasala irrigation project near Pune, in the command of distributory No. 5 and 6 of old Mutha right bank canal. The drainage scheme for 30 ha was designed for reclamation of waterlogged black cotton soils of Mahatma Phule Krishi Vidyapeeth Rahuri 1981. The main causes of waterlogging were seepage from Mula right bank canal, excess irrigation on the upper part of field and percolation tank on the upper boundary of the field. The subsurface drainage system was provided after detailed drainage investigations. Though there were some success stories in past indicating identification of drainage problem and competence to tackle it, major achievements could be accomplished during the last forty years when a subsurface drainage based reclamation package was developed and implemented to cover about 66084 ha of waterlogged saline lands in eleven states of the country. Field studies at Bidaj (Gujarat) with open drains at a 15, 20 and 25 m drain spacing and 1.5 m depth in heavy textured highly saline soil and medium to high saline ground water resulted in an overall improvement in the salinity status of soil. Subsurface horizontal drainage provided in *Vertisols* of Mahi-Kadana command at Dabhou in Gujarat showed significant improvement in the root zone salinity conditions. Considering the severity and extent of waterlogging and secondary salinization problems in *Ukai Kakrapar* Command (UKC), Soil and Water Management Research Unit, Navsari Agricultural University (formerly Gujarat Agricultural University), Navsari conducted studies on subsurface drainage in 56 ha block at the farmers' fields situated in the jurisdiction of Chalthan Sugar Factory, Chalthan during 1984-85 to 1991-92. After installation of subsurface drainage, paddy and sugarcane yields were higher as compared to pre drainage yields. The pH and EC values also showed a decreasing trend with the progress of time after drainage. Similarly, Water and Land Management Institute, Anand (Gujarat) also conducted pilot scale demonstrations of subsurface drainage technology in Mahi Right Bank Canal Command during 1990-91. The soils were extremely saline and waterlogged and the area was almost lying barren. After installation of subsurface drainage, paddy crop was grown and yield level of 2 to 3 t/ha was achieved. Under Indo-Dutch Network Project, two pilot areas were selected in Ukai-Kakrapar Command. The important characteristics of both the pilot areas are given in Table 8. The distinct difference between both the pilot areas was cropping intensity *i.e.* in Segwa it was 116 per cent and only 48 per cent in Sisodara. This was mainly because of severity of waterlogging and salinity problems were more in Sisodara than in Segwa. The cropping intensity of 48 per cent in Sisodara suggests presence of barren land in pilot area. After completion of pre-project survey and analysis of drainage related parameters of soil, drainage design details were worked out and system installation work was initiated during 1998.

Table 8. Important characteristics of pilot area under subsurface drainage

S N	Particulars	Pilot area	
		Segwa	**Sisodra**
1.	Taluka/district	Kamrej/Surat	Ankleshwar/Bharuch
2.	Climate	Sub humid	Semi-arid
3.	Branch/minor	Surat branch/Segwa minor	Kosamba branch /Pandvai Minor
4.	Size of pilot area (ha)	188	169
5.	Cropping intensity (%)	116	48
6.	Major crops	Sugarcane, paddy	Sugarcane, paddy
7.	Major constraints	Waterlogging and initiation of salinization	Extreme waterlogging and high salinity/sodicity
8.	Source of irrigation water (ha)		
	Canal	76	76
	Well alone	37	--
	Drain	4	--
	Conjunctive use	26	--

At Segwa pilot site, singular and composite closed subsurface drainage (CSSD) systems were installed at 30, 45 and 60 m spacing with and without amendment and envelope. In all, 28.1 ha area was brought under CSSD in phased manner. While at Sisodara, only open subsurface drainage (OSSD) was laid out in 16 ha area with 30 and 60 m drain spacing. Both these pilot areas were monitored rigorously for soil, drain water, ground water level and crop yield parameters. The soluble salt content in soil (0-90 cm) under CSSD decreased from initial value of about 4.0 dS/m in 1998 to 1.0 dS/m in 2002. Similarly sodicity was also tended to decrease after installation of CSSD system at Segwa. Also there was increase in sugarcane yields with time by 35 percent as yield increased from 78-104 to 105-140 t/ha. In village Mulad, Taluka Olpad, district Surat, the salt affected *Vertisols* under sugarcane cultivation measuring about 45 hectare has been brought under the SSD with financial help from Nagar Palika Surat. The project was implemented during 2012 and till date is working successfully and farmers are reaping the good harvest from sugarcane crop with increment in yield to the tune of 2.5 to 3.0 times as compared to situation before SSD. By looking in to the success of the project individual farmers of the village and nearby villages have adopted SSD in their own fields and reaping benefit. The subsurface drainage system was also installed in the area of 8.81 ha in challis biga farm of ARS, Kasabe Digraj with salinity and waterlogging problem. The electrical conductivity ranged from 2.22 to 17.82 dS/m. The exchangeable sodium percentage was recorded in the range of 7.04 to 17.50. The hydraulic conductivity was 0.0236 to 0.0579 m/day. The water table fluctuation was recorded in the range of 0.265 to 1.85 m from the surface in different seasons. Perforated corrugated PVC pipes of 80 mm diameter was used for collector drain. The average depth of collector and lateral drains was 1.32 m. The spacing between two laterals was 25 m. Coarse sand filter and synthetic filter were used as filter envelope. The drainage inspection chambers were installed on collector drain. The drainage effluent was taken out by gravity and expenditure on pumping is minimized. The installation of drainage system could help to bring these barren soils under cultivation. Improvement in the crop yields was observed and during one year, EC and ESP both were decreased down by 5 to 6 units. A pilot project in waterlogged saline *Vertisols* of villages Ghodadara and Adadara in Bharuch district has been undertaken in the year 2016 with different drain spacing at 30 and 35 meters, respectively in one hectare area each. After installation of SSD and after first rainy season, it is found that the average EC_2 values of different soil layers up to 1.2 m depth at village Adadara site was reduced to 3.63-6.67 dS/m from 4.43-7.30 dS/m. The electrical conductivity of soils at surface layer at Adadara site was reduced up to 50% (EC_2 = 3.6 dS/m) from its initial EC_2 (7.6 dS/m).

Conclusion

The black cotton soils (*Vertisols*) are heavy textured soils with low permeability and are more prone to waterlogging and soil salinity if irrigated without proper drainage. These soils can be reclaimed by installing subsurface drainage system with proper design specifications. However drain spacing has to be kept smaller as compared to alluvial soils of Haryana and Punjab. At places where gravity outlets are available for the disposal of drainage water which reduces the pumping cost of the system, the success of SSD is visible in *Vertisols*. It has been proved that subsurface drainage is a successful technology to reclaim waterlogged and saline *Vertisols*. Considering the encouraging results of different studies, large scale implementation SSD project for reclamation of waterlogged saline heavy textured *Vertisols* in canal irrigated areas of Gujarat may be recommended. However, for large scale projects, environmental concerns on disposal of large volume of saline drainage water needs to be taken into consideration. Moreover, periodic monitoring of the system is required to carry out in order to check the effectiveness and efficiency of the system for better performance and effective leaching of salts.

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Protocols for Soil Sampling, Soil and Water Analysis

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Soil samples collection

Soil sampling includes collection of samples from field and its preparation for the analytical work. It has to be undertaken with utmost care as all the interpretation and recommendations are based on the analysis of this representative sample.

Tools required for soil sampling

The tools used for soil sampling includes Auger, Spade, Khurpa, Measuring tape or Scale Polythene paper Bags ,Cloth bag, marker pen, Information Sheet/Label.

Collection of soil sample

Prepare the farm map, showing the field number/ survey number, boundaries. Where the areas within field differ distinctly in appearance they may be indicated in map. Depending on the farm size, topography the sample is to be collected from different spots/field. The sample may be collected after leaving some gap from the farm periphery/boundary. A composite sample from each field has to be taken. Scrape the surface litter *viz* grass, pebbles, and stones preferably to a distance of 30 cm on all the side. Take a uniform care of the soil from the surface plough (15 cm) with a soil auger or a v shaped cut up to a depth of 15 cm with a spade or khurpa. Take about 4 to 6 cm thick uniform slice of soil parallel to the V shaped cut. Depending on the field size about 6-10 samples are to be taken at random, Collect all these samples in a tray, mix all the soil samples collected from different spots and mix them well. Divide the mixed sample in four equal parts and make heap. Mix two diagonal heaps and repeat the process to get a uniform representative sample about two Kilograms. Similarly take the 2nd sample from the depth of 15-30 cm. Now label the polythene bag and the cloth bag with marker pen. Put the collected soil sample in the polythene bag and close the bag with rubber band or staple with stapler pin. Now prepare two labels preferably of thin card board indicating the following information

1. Name and the address of the farmer
2. Field Location and Survey number
3. Crop taken if any or crop to be taken.
4. Date of sampling.

Put one label inside the cloth bag and put the sample collected in polythene bag into the cloth bag and tightly tie after putting the another label on the outside the mouth of the cloth bag.

The sample collected may be sent to nearest soil laboratory.

Precautions:

1. Sample may not be collected from unusual spots like farm fence, bunds, marshy/wet spots , fertilized soils,
2. Samples may not be collected from the place where compost pit or water storage tank or irrigation source like tube well is located
3. The presence of artifacts (pieces of bricks, pottery *etc*. or other evidence of man's activity occurring below the plough layer should be recorded as evidence of disturbance of very long period of cultivation

4. In no case the label should be put inside the polythene bag. In case of sampling from salt affected soils, proper care has to be taken while sampling. Salt crust visible n the surface should be sampled separately with recording of appropriate depth of sampling. Subsequently, the samples should be collected from the surface and the subsurface horizon up to a depth of about a meter or so, preferably at interval 0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm, 60-90 cm, 90-120 cm.

Preparation of soil samples in the laboratory

Once the soil sample is received in the laboratory, all the information furnished on the sample bag are recorded in the register thereafter the bag is opened and all the information on inner label and the polythene bag are tallied. If there is any discrepancy the same is brought to the notice of the sample collector/ or the agency giving the sample for analysis. The sample is then air dried in shade to prevent the loss of nutrients. The pebbles, small stones, gravel if any, leaves, grass and such particles are removed and recorded separately. The weight of stones/ pebbles, gravel *etc*. may also be recorded to determine their percentage on the basis of total soil weight. When the sample is completely dried, a part of the sample (about 500 g) is retained for determination of macro morphological, micro morphological, microbial and hydrological characteristics. The remaining soil is grinded in mortar pestle or in the soil grinder and is passed through 2 mm sieve; the sample is mixed thoroughly and is stored after proper labeling

Preparation of saturation extract

Soil salinity is conventionally defined and measured on the aqueous extract of the saturated soil paste.

Material required: Plastic Beakers (500 ml capacity), Spatula, Glass Rod, Buchner Funnel, Filter paper, Vacuum Pump *etc*

How to extract:

Take about 250 to 300 g of air dried soil in the beaker; add sufficient water to moisten the soil, stir with glass rod and add water till the soil is saturated. Leave the sample overnight, to get the soil fully saturated, Next day again stir the sample with glass rod, and add more water if required, at the saturation the soil paste glistens, flows slightly when the container is tilted, the paste slides smoothly of spatula/ glass rod and if a depression is made in the surface, no water collects in it and the depression slowly fills up by the flow of the paste. Allow the sample for about half an hour, remove the glass rod/ spatula and take the pH of the paste, with pH meter, it is indicated as pH of soil paste with abbreviation pH_s.

Transfer the contents of the beaker (saturated soil paste) to a Buckner funnel having the moisten filter paper fitted on vacuum flask, apply the vacuum, collect the extract. Once the sufficient quantity of extract is received the same is transferred to a plastic bottle which is labeled. Immediately after transferring the extract, take the electrical conductivity of the extracted solution with conductivity meter which is indicated as electrical conductivity of extract and depicted by the abbreviation EC_e having the unit dS/m. This extract is also used for determination of soluble cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}) and anions such as carbonate (CO_3^{2-}), bicarbonate (HCO_3^{-}), chloride (Cl^{-}) and sulphate (SO_4^{2-}).

Determination of soil pH and the electrical conductivity (EC) in 1: 2 ratio

Materials required: Glass beakers (100 ml capacity), Distilled water, Conductivity meter, and pH meter, Standard stock solution of 0.1 N KCL, standard buffer solutions of 4.0, 7.0 and 9.2 pH

Method: Take 25 g of the air dried sample in 100 ml beaker and add 50 ml of distilled water keep for few minutes and stir the contents with glass rod at an interval of 15-20 minutes after about three to four stirrings, keep the samples undisturbed for 2-2.5 hours.

Determination of electrical conductivity:

Standardize the conductivity meter with 0.1 N KCl solution (7.456 g dry KCl in 1 liter of distilled water). Once the instrument is standardized, dip the conductivity cell in the supernatant solution/layer without disturbing the soil and take the reading. The reading observed is represented with abbreviation EC_2 ($dS/\ m^{-1}$)

Determination of pH:

Once the electrical conductivity is taken the sample is thoroughly stirred for taking the pH. The pH meter is standardized with the Buffers of 4.0 pH and 7.0 pH standards for two point calibration units and with 4.0, 7.0 and 9.2 pH buffer standards for three point calibration units. Once the pH meter is standardized, the electrode of the pH meter is dipped in the soil sample solution and the reading is recorded. In determining EC and pH care has to be taken that the electrodes do not touch the walls or the bottom of the beaker (Jakson, 1973). The pH reading observed is represented with abbreviation pH_2.

Analysis of soil saturation extract:

Sodium in the saturation extract is determined by flame photometer

The Standard stock of 1000 ppm sodium chloride is prepared (Dissolve 2.542 g of Sodium chloride-AR in one liter of double distilled water) which is further diluted to 10 ppm, 20 ppm, 40 ppm, 60 ppm, 80 ppm and 100 ppm. The flame photometer is calibrated with 20 ppm, 40 ppm, 80 ppm and 100 ppm of the stock solution of sodium chloride. Feed the extract and take reading, if the unit display "out of range" then pipette a known volume of the extract in 25 ml or 50 ml volumetric flask and make up the volume with double distilled water. Feed this solution to the atomizer of the flame photometer and take the readings.

$$Na^{+}\ (ppm) = Na^{+}\ \text{concentration in ppm} \times \text{dilution factor}$$

$$Na^{+}\ (me/l) = \frac{Na^{+}\ \text{concentration in ppm} \times \text{dilution factor}}{23}$$

Potassium in the saturation extract is determined by flame photometer

The Standard stock of 1000 ppm potassium chloride is prepared (Dissolve 1.909 g of potassium chloride-AR in one liter of double distilled water) which is further diluted to 10 ppm, 20 ppm, 40 ppm, 60 ppm, 80 ppm and 100 ppm. The flame photometer is calibrated with 20 ppm, 40 ppm, 80 ppm and 100 ppm stock solution of potassium chloride. Feed the extract and take reading, if the unit display "out of range" then pipette a known volume of the extract in 25 ml or 50 ml volumetric flask and make up the volume with double distilled water. Feed this solution to the atomizer of the flame photometer and take the readings.

$$K\ (ppm) = K\ \text{concentration in ppm} \times \text{dilution factor}$$

$$K\ (me/l) = \frac{K\ \text{concentration in ppm} \times \text{dilution factor}}{39}$$

Calcium and magnesium in saturation extract:

Reagents required: Standard solution of ethylene diamine tetra acetic acid (EDTA- versanate solution) 0.01 N**:** Dissolve 2 g of EDTA disodium salt in about 800 ml of distilled water, transfer the same to one liter volumetric flask and make up the volume to one liter with distil water, Murexide indicator: Take 0.2 g ammonium perpurate and 40 g potassium sulphate in mortar and pestle and mix them to get homogeneous powder, store in plastic bottle, Sodium hydroxide 4N (Dissolve 40 g of NaOH in 250 ml distilled water), NH_4Cl + NH_4OH buffer: Dissolve 16.875 g of Ammonium chloride in 142.5 ml of Ammonium hydroxide and make the volume to 250 ml in volumetric flask, Erichrome black T indicator (EBT): Take 100 ml ethanol and dissolve 4.5 g of hydroxylamine hydrochloride and add 0.5 g of EBT indicator powder.

Method

Determination of calcium plus magnesium: Take 2 ml of the extract and add about 20 ml of distilled water and add 10-12 drops of NH_4Cl+ NH_4OH buffer, titrate the same against 0.01 N EDTA using EBT. The colour changes from pinkish red to Sky blue colour.

$$Ca^{2+} + Mg^{2+} \text{ (me/l)} = \frac{\text{Volume of EDTA consumed} \times \text{Normality of EDTA} \times 1000}{\text{Volume of aliquot taken (ml)}}$$

Determination of calcium: Take 2 ml of the extract and add about 20 ml of distilled water and add 0.1g of Muroxide indicator, and 10-12 drops of 4N Sodium Hydroxide buffer titrate the same against 0.01 N EDTA. The colour changes from light pink to violet colour.

$$Ca^{2+} \text{ (me/l)} = \frac{\text{Volume of EDTA consumed} \times \text{Normality of EDTA} \times 1000}{\text{Volume of aliquot taken (ml)}}$$

$$Mg^{2+} \text{ (me/l)} = \text{(Ca+Mg)} - \text{Ca}$$

Determination of carbonate, bicarbonate, chloride and sulphate in saturation extract

Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-)

Reagents required: Micro-burette 10 ml capacity, Phenolphthalein & Methyl Orange indictor, 0.01N or 0.1 N sulphuric acid (standardize), 50 ml conical flask or porcelain dish (25-50 ml capacity)

Method for carbonate: Take 2 ml of saturation extract in a 50 ml conical flask or porcelain dish, add two drops of the phenolphthalein indictor, If the solution gives pink colour, it indicate the presence of the carbonate, titrate this solution with 0.1 N or 0.01 sulphuric acid adding drop wise till the pink colour disappear, note the volume of acid consumed (A).

Method for bicarbonate: To the solution in which carbonate has been determined as above, add two drops of the methyl orange indictor, the solution will turn yellow, or reddish yellow colour titrate this solution with 0.1 N or 0.01 sulphuric acid adding drop wise till the colour change to red /rose red, note the volume of acid consumed (B).

$$CO_3^{2-} \text{ (me/l)} = 2\text{ A} \times \frac{\text{Normality of sulfuric acid} \times 1000}{\text{Volume of aliquot taken (ml)}}$$

$$HCO_3^{2-} \text{ (me/l)} = \text{(B - 2A)} \times \frac{\text{Normality of sulfuric acid} \times 1000}{\text{Volume of aliquot taken (ml)}}$$

Where, A= volume (ml) of the sulphuric acid consumed i.e. disappearance of pink colour

B = volume (ml) of the sulphuric acid consumed *i.e.* change of colour from yellow to rose red

Chloride (Cl^-)

Reagents and material: Potassium Chromate indicator (Dissolve 5 g of Potassium Chromate in 100 ml distilled water), Standard 0.01 Silver Nitrate (Dissolve 1.791 g of $AgNO_3$ in one liter of distilled water), 50 ml conical flask or porcelain dish.

Method: Take 2 ml of fresh aliquot, add two drops of the potassium chromate indictor, the solution will turn yellow, or reddish yellow colour, titrate this solution with 0.1N or 0.01N silver nitrate adding drop wise till the red colored permanent precipitates appears.

$$Cl^- \text{ (me/l)} = \frac{\text{Volume of } AgNO_3 \text{ consumed} \times \text{Normality of } AgNO_3 \times 1000}{\text{Volume of aliquot taken (ml)}}$$

Sulphate (SO_4^{2-})

Determination of sulphate in soil extract by tubimetric method. The tubidimetric method of sulphur determination was given by Chesnin and Yien (1951).

Reagents & material: Sodium acetate Acetic acid buffer (Morgan reagent): Dissolve 100 g Sodium acetate trihydrate in 800 ml distilled water and add 30 ml of 99.5 % Acetic Acid and make volume to 1 liter, Gum acacia: Dissolve 0.25 g gum acacia in 100 ml distilled water and filter the solution to get clear solution, Barium chloride: Grind the barium chloride crystal to make fine powder, Standard sulphur solution 100 ppm S: Dissolve 0.5434 g of Potassium Sulphate in distilled water and dilute to 1 liter.

Standard curve: Pipette 0, 0.2, 0.4, 0.8, 1.0, 2.0, 3.0, 4.0 and 5.0 ml from 100 ppm standard S solution to get 0, 0.8, 1.6, 3.2, 4.0, 8.0, 12.0, 16.0 and 20.0 ppm S concentration in 25 ml volumetric flask add 5 ml sodium acetate-Acetic acid buffer, 1 ml gum acacia, add 0.5 g barium chloride and add distilled water and make up the volume, shake for 1 minute, take turbidity readings at 420 nm within 5 to 20 minutes.

Method: Take 2 ml of saturation extract in 25 ml volumetric flask and add 5 ml sodium acetate-acetic acid buffer, 1 ml gum acacia. Add 0.5 g barium chloride and add distilled water and make up the volume, shake for 1 minute. Take turbidity readings at 420 nm within 5 to 20 minutes.

Calculations:

Volume of extract taken	= 2 ml
Dilution (2 ml to 25 ml=12.5times)	= 12.5 times
% Transmission (Reading of Spectrophotometer)	= T
S as obtained from standard curve (ppm)	= y
Sulphur in extract (ppm)	= y × dilution= y × 12.5= Z
SO_4^{2-} in extract (ppm)	= Z × 3
SO_4^{2-} in extract (me/l)	= (ppm of SO_4^{2-})/ mol. wt. of SO_4^{2-}

Determination of exchangeable sodium, potassium, calcium and magnesium in neutral soils

Exchangeable sodium and potassium

Reagents: 1 N neutral ammonium acetate of 7.0 pH: Dissolve 77.08 g of ammonium acetate dissolved in about 800 ml of distilled water and pH adjusted to 7.0 with ammonium hydroxide or acetic acid, make the final volume to 1liter.

Method: Take 5 g of soil in 100 ml conical flask and add 25 ml of 1N ammonium acetate solution shake the contents on the mechanical shaker for 20-30 minutes and filter and the make up the volume to 25 ml.

Determine sodium, potassium on flame photometer as mentioned above and calcium & magnesium by EDTA titration.

$$\text{Exch. } Na^+ \text{ (ppm)} = \frac{Na^+ \text{ conc. from standard curve (ppm)} \times \text{Volume of extractant (ml)}}{\text{Wt. of soil (g)}}$$

$$\text{Exch. } Na^+ \text{ (me/100g or cmol(p+)/kg soil)} = \frac{\text{Exch. } Na^+ \text{ (ppm)}}{(23 \times 10)}$$

$$\text{Exch. } K^+ \text{ (ppm)} = \frac{K^+ \text{ conc. from standard curve (ppm)} \times \text{Volume of extractant (ml)}}{\text{Wt. of soil (g)}}$$

$$\text{Exch. } K^+ \text{ (me/100g or cmol(p+)/kg soil)} = \frac{\text{Exch. } K^+ \text{ (ppm)}}{(39 \times 10)}$$

Determination of exchangeable calcium and magnesium in calcareous soils

Reagents required: 1 N potassium chloride + tri-ethanol amine (TEA) solution (KCL-TEA solution): Dissolve 74.6 g of KCl in about 500 ml distilled water and add 25 ml of TEA (Sp-gr.1.12) and stir well dilute the solution to 850 ml with distilled water and adjust the pH to 8.5 with 1.0 N HCl, Standard solution of ethylene diamine tetra acetic acid (EDTA- versanate solution) 0.01 N: Dissolve 2 g of EDTA disodium salt in about 800 ml of distilled water, transfer the same to one liter volumetric flask and make up the volume to one liter with distilled water, Murexide indicator: (0.2 g ammonium purpurate + 40 g of potassium sulphate, take both the reagents in mortar and pestle and mix them to get homogeneous powder, store in plastic bottle, Sodium hydroxide 4N (Dissolve 40 g NaOH in 250 ml distilled water), NH_4Cl + NH_4OH buffer: Dissolve 16.875 g of Ammonium chloride in 142.5 ml of Ammonium hydroxide and make the volume to 250 ml in volumetric flask, Erichrome black T indicator (EBT): Take 100 ml ethanol and dissolve 4.5 g of hydroxylamine hydrochloride and add 0.5 g of EBT indicator powder.

Method: Weigh 10 g of air dry soil sample in 100 ml beaker and add 40 ml of KCL-TEA solution, stir the contents thoroughly with glass rod for three to four times at an interval of 20 minutes. Filter the content through Watman No. 40 filter paper and collect the leachate in 100 ml volumetric flask, further leach the content with 20 ml KCL-TEA to bring the volume of aliquot to 100 ml.

Determination of calcium plus magnesium: Take 5 ml of the extract and add about 25 ml of distilled water and add 10-12 drops of ammonium chloride–ammonium hydroxide buffer titrate the same against 0.01 N EDTA using EBT. The colour changes from pinkish red to sky-blue colour.

Determination of calcium: Take 5 ml of the extract and add about 25 ml of distilled water and add 0.1 g of murexide indicator, and 10-12 drops of 4N sodium hydroxide buffer titrate the same against 0.01 N EDTA. The colour changes from light pink to violet colour.

Calculations

$$Ca^{2+}+Mg^{2+}\ (me/100g) = \frac{\text{Vol. of EDTA used (ml)} \times \text{Normality of EDTA} \times \text{Volume of extract (ml)} \times 100}{\text{weight of soil sample taken (g)} \times \text{aliquot taken (ml)}}$$

$$Ca^{2+}\ (me/100g) = \frac{\text{Vol. of EDTA used (ml)} \times \text{Normality of EDTA} \times \text{Volume of extract (ml)} \times 100}{\text{weight of soil sample taken (g)} \times \text{aliquot taken (ml)}}$$

$$Mg^{2+}\ (me/100g) = [Ca^{2+}+Mg^{2+}\ (me/100g)] - [Ca^{2+}\ (me/100g)]$$

Determination of cation exchange capacity (CEC)

Materials required: Funnel, beaker, filter paper, flame photometer, volumetric flask

Reagents: Sodium acetate (1.0 N): Dissolve 136 g of sodium acetate tri hydrate in distilled water and adjust the pH to 8.5 using sodium hydroxide or acetic acid, Ammonium acetate (1.0 N): Dissolve 77.08 g of Ammonium Acetate dissolved in about 800 ml of distilled water and adjust pH to 7.0 with Ammonium hydroxide or Acetic acid, make the final volume to 1liter, Ethanol 60%, Standard stock solution of sodium chloride: Dissolve 2.338 g of dry sodium chloride in 1 liter this will give 40 me/l Na stock solution, 4 me/l Na stock: Take 25 ml from stock solution from 40 me/l Na solution and make the volume to 250 ml in 250 ml volumetric flask.

Preparation of working standards and calibration of flame photometer

Pipette out 0, 5, 10, 15, 20, 25, 50 and 75 ml from 4 me/l Na stock in 100 ml volumetric flask and make the volume to 100 ml by adding 1 N ammonium acetate. This will result 0.0, 0.2, 0.4, 0.6, 0.8, 1, 2, and 3 me/l sodium concentration. Calibrate the flame photometer using above standard stocks.

Method: Weigh 5 g of soil in a 150 ml beaker and add 33 ml of 1N sodium acetate and keep overnight to saturate the soil with sodium, transfer the contents to funnel fitted with moist Whatman No. 42 filter paper. Once the leaching of overnight solution is over, add 33 ml of sodium acetate. Repeat the process for three to four times, discard the leachate. Once the leaching is completed, add 30 ml of 60% ethanol and leach to remove excess of sodium acetate, and check the electrical conductivity (EC) of the leachate obtained, continue the leaching process with ethanol until the EC of leachate is between 40-55 micro mhos per centimeter. Discard the leachate of ethanol. Once the ethanol leaching is over, replace the beaker with 100 ml volumetric flask and add 33 ml of 1 N ammonium acetate to replace the adsorbed sodium from sample. Continue the process by adding 33 ml of ammonium acetate to get 100 ml of the extract. Determine the sodium concentration by flame photometer.

$$CEC\{cmol(p+)\ kg^{-1}\} = \frac{\text{Na (me/l) from the standard curve} \times 10}{\text{Weight of the soil sample (g)}}$$

Determination of exchangeable sodium percent (ESP)

Materials required: Funnel, beaker, filter paper, flame photometer, volumetric flask

Reagents required: Ammonium acetate (1.0 N): Dissolve 77.08 g of ammonium acetate dissolved in about 800 ml of distilled water and adjust pH to 7.0 with ammonium hydroxide or acetic acid, make the final volume to 1liter, Ethanol 60%, Standard stock solution of sodium chloride: Dissolve 2.338 g of dry sodium chloride in 1 liter this will give 40 me/l Na stock solution, 4 me/lit Na stock: Take 25 ml from 40 me/l Na solution and make the volume to 250 ml in 250 ml volumetric flask.

Preparation of working standards and calibration of flame photometer

Pipette out 0, 5, 10, 15, 20, 25, 50 and 75 ml from 4 me/l sodium stock in 100 ml volumetric flask and make the volume to 100 ml by adding 1 N ammonium acetate. This will result 0.0, 0.2, 0.4, 0.6, 0.8, 1, 2, and 3 me/l Na concentration. Calibrate the flame photometer using above standard stocks.

Method: Take 5 g of soil on 9.5 cm dia. or 11 cm dia. funnel fitted with Whatman filter paper No 42, moisten the soil with distilled water to remove air bubbles. Add 33 ml of 60 % ethanol and allow to leach, continue the leaching for another two to three times with 33 ml of 60 % ethanol, check the EC of the leachate, and add another 33 ml of ethanol portions till the leachate conductivity is between 40-55 micro mhos per cm. Once the leaching with ethanol is over, add 33 ml of 1N ammonium acetate and collect the leachate in 100 ml volumetric flask, continue the process by adding 33 ml of Ammonium Acetate to get 100 ml of the extract.

$$\text{Exchangeable Na (me/100 g soil)} = \frac{\text{Na concentration of the extract in me/l} \times 10}{\text{Weight of the soil sample (g)}}$$

$$\text{ESP} = \frac{\text{Exchangeable Na me/100 soil}}{\text{CEC}}$$

Determination of total nitrogen (Kjeldhal method)

Materials required: Nitrogen analyzer, consisting of Digestion unit attached with exhaust system and distillation unit, conical flask 250 ml capacity. Micro burette of 10 ml

Chemicals required: Concentrated sulphuric acid, Catalyst/ Digestion mixture: 50 g of Sodium or potassium sulphate and 5 g of copper sulphate mixed together, 4% Boric acid: 40 g of Boric acid –AR dissolved in one liter of distilled water, Mixed indicator: 0.3 g of Bromocresol green (BCG) indicator powder and 0.2 g of Methyl red mixed in 400 ml of 90% ethanol, 40 % Sodium Hydroxide: 400 g of sodium hydroxide dissolved in 1 liter of distilled water, for titration: 0.1N hydrochloric acid or sulphuric acid (standardized).

Method: Take 1 g of the soil sample into the digestion tube, add about 5-7 g of digestion mixture and 20 ml of concentrated sulphuric acid, load the insert rack in the digestion block (20 samples at a time) place the exhaust hood on the tubes, and switch on the exhaust unit then heat the digestion block at a temperature of 375^0 C for about 2 to 3 hour till the digestion is completed, The sample turns colour less or light green colour at the end of the digestion. Switch off the digester and remove the tubes with exhaust led intact and place them on the tube support rack and allow them to cool to room temperature. (Continue the exhaust system to run till tubes are cooled to room temperature and fumes cease out /stops from the tubes).

Distillation process: Pipette 10 ml of the 4 % boric acid in 250 ml conical flask and add two drops of mixed indicator place, the conical flask in the distillation chamber and dip the outlet tube/receiver tube in boric acid. Add 25 ml of 40 % sodium hydroxide in digestion tube and start distillation, collect distillate of about 150 ml.

Remove the conical flask from the distillation chamber, and allow to cool down to room temperature. Titrate this distillate with 0.1 N hydrochloric acid or sulphuric acid till the colour changes from green to red/pinkish red. Run a blank sample without soil sample.

$$\% \text{ TN} = \frac{\text{Vol. of the acid used (sample titer value-blank titer value)} \times \text{normality of acid} \times 14 \times 100}{\text{sample weight (g)} \times 1000}$$

Determination of available mineralizable nitrogen

Reagents: 0.32% Potassium Permanganate: 3.2 g of potassium permanganate in 1 liter of distilled water, 2.5 % sodium hydroxide: 25 g of NaOH–AR in one liter distilled water, 4% Boric acid: 40 g of boric acid –AR dissolved in one liter of distilled water, Mixed indicator: 0.3 g of bromo-cresol green (BCG) indicator powder and 0.2 g of Methyl red mixed in 400 ml of 90% ethanol, 0.1 N H_2SO_4: Standardize with 0.1N Na_2CO_3 using methyl orange indicator.

Method: Transfer 5 g of soil sample in distillation tube and moisten with distilled water (5 ml) and add 25 ml of 0.32 % potassium permanganate and load the digestion tube in the distillation unit.

Distillation process: Pipette 10 ml of the 4 % boric acid in 250 ml conical flask and add two drops of mixed indicator, place the conical flask in the distillation chamber and dip the outlet tube/receiver tube in boric acid. Add 25 ml of 2.5 % sodium hydroxide in digestion tube and start distillation, collect distillate of about 150 ml, remove the conical flask from the distillation chamber, and allow it to cool to room temperature. Titrate this distillate with 0.1 N hydrochloric acids or sulphuric acid till the colour changes from green to red/pinkish red. Run a blank sample without soil sample.

1 ml 1N H_2SO_4 = 0.014 g N

$$\text{Available N (kg/ha)} = \frac{\text{Vol. of acid (Sample titer value-Blank titer value)} \times \text{N of Acid} \times 0.014 \times 100 \times 10{,}000 \times 2.24}{\text{Sample weight (g)}}$$

Determination of available phosphorus

Soil available phosphorus is determined by extracting soil with 0.5M $NaHCO_3$ at pH 8.5 for neutral-alkaline soils and determining P from the filtrate by spectrometric method (Olsen *et al*., 1954).

Olsen's method using ascorbic Acid

Reagents: 0.5 N Sodium Bicarbonate: Dissolve 42 g of sodium bicarbonate (AR grade) in 800 ml distilled water and adjust the pH to 8.5 with dilute sodium hydroxide or hydrochloric acid, Activated phosphorus free charcoal or Darco G -60 AR (P free; to obtain P-free charcoal, 80 g charcoal material as a slurry in distilled water leached overnight with 1 liter of 6M HCl in 60 mm diameter column (250 ml capacity) and then with deionized water till the leachate is free of chloride, then material is dried at 110^{0}C) (Sarirullah *et al.*, 1990), Ammonium molybdate P- reagent: Dissolve 20 g of AR ammonium molybdate in 250 ml of distilled water. In another beaker dissolve 0.291 g antimony potassium tartarate in about 100 ml distilled water. Both these reagents are added to one liter of 5N sulphuric acid (140 ml sulphuric acid per liter) mix thoroughly and make the volume to 2 liters with distilled water, Ascorbic acid: 1.056 g of ascorbic acid is dissolved in 200 ml of ammonium molydate P-reagent (it has to be prepared a fresh as and when required), P-Nitrophenol: Dissolve 0.5 g of p-nitrophenol in 100 ml of distilled water, 5N sulphuric Acid: Dilute 140 ml concentrated Sulphuric acid to one liter, Standard

Phosphorus solution: Dissolve 0.4393 g of AR grade potassium dihydrogen orthophosphate (KH_2PO_4) in distilled water and make the volume to one liter. This will provide 100 ppm P solution. Dilute 50 ml of this solution to 1000 ml and this will be 5 ppm working standard stock solution.

Method: Take 2.5 g of soil sample in 150 ml conical flask. Add about 1 g of phosphorus free activated charcoal and 50 ml of 0.5 N sodium bicarbonate solutions. Shake the contents on mechanical shaker for 30 minutes and filter them immediately through Whatman filter paper 40. Pipette out 5 ml aliquot in 25 ml volumetric flask, add 2 drops of p-Nitrophenol indicators, it develops yellow colour, add 5 N sulphuric acid drop wise till the colour disappear, shake the conical flask to remove dissolve gases, and keep the contents for two hours to make it free from dissolve gases. Then add 10 ml of distilled water and 5 ml of ascorbic acid solutions. Make the volume to 25 ml. Blue colour so developed is measured at 882 nm after calibrating the spectrophotometer with known standards. Prepare a blank sample without soil.

Standard curve: Take 0, 1 ml, 2 ml, 3 ml, 4 ml and 5 ml of working standard stock solution5 ppm P in 25 ml flask to prepare 0.0, 0.2, 0.4, 0.6, 0.8 and 1 ppm P solutions, to these add 5 ml of 0.5 N sodium bicarbonate (8.5 pH), add 2 drops of p-Nitrophenol indicators, it develops yellow colour, add 5 N sulphuric acid drop wise till the colour disappear, shake the conical flask to remove dissolve gases, and keep the contents for two hours to make it free from dissolve gases. Then add 10 ml of distilled water and 5 ml of ascorbic acid solutions. Make the volume to 25 ml, blue colour so developed is measured at 882 nm.

$$P_2O_5\text{ (kg/ha)} = \frac{\text{R (ppm)} \times \text{Vol. of extractant (ml)} \times \text{volume make up (ml)} \times 2.24 \times 2.29}{\text{Wt. of soil (g)} \times \text{Aliquot taken (ml)}}$$

R= Conc. of P (ppm) from standard curve

Olsen's method using stannous chloride

Reagents: 0.5 N Sodium Bicarbonate: Dissolve 42 g of sodium bicarbonate (AR grade) in 800 ml distilled water and adjust the pH to 8.5 with dilute sodium hydroxide or hydrochloric acid, Activated phosphorus free charcoal or Darco G -60 AR, 1.5 % ammonium molybedate: Dissolve 15 g ammonium molybdate in 300 ml warm distilled water. Allow the solution to cool, then add 410 ml of concentrated hydrochloric acid gradually with mixing and dilute the solution to one liter with distilled water, Stannous chloride: Dissolve 10 g of stannous chloride in 25 ml concentrated hydrochloric acid (the solution is highly unstable and has to be prepare a fresh and to be stored in amber bottle, Working solution of stannous chloride: Take 0.5 ml of the above stock and dilute to 66 ml with distilled water, Standard P solution (50 ppm): Dissolve 0.2195 g of AR grade potassium dihydrogen orthophosphate (KH_2PO_4) in distilled water and make the volume to one liter this will provide 50 ppm P solution. Dilute 40 ml of this solution to 1000 ml, this will be 2 ppm working standard stock solution,

Method: Take 2.5 g of soil sample in 150 ml conical flask and add about 1 g of phosphorus free activated charcoal and 50 ml of 0.5N sodium bicarbonate solution. Shake the contents on mechanical shaker for 30 minutes and filter them immediately through Whatman filter paper 40. Pipette out 10 ml of aliquot in 50 ml volumetric flask, add 10 ml of 1.5% ammonium molybedate and about 2-3 ml of distilled water, shake well, add 1 ml of working stannous chloride and make up the volume to 50 ml with distilled water, the blue colour is developed. Read the OD at 660 nm wavelength on spectrophotometer within 10-20 minutes.

Standard: Take 0, 1 ml, 2 ml, 3 ml, 4 ml, 5 ml, 6 ml, 7 ml, 8 ml, 9 ml and 10 ml of working standard stock solution 2 ppm P in 50 ml flask to prepare, 0.0, 0.04, 0.08, 0.12, 0.16, 0.20, 0.24, 0.28, 0.32, 0.36 and 0.40 ppm P. Add 10 ml of 0.5 N sodium bicarbonate (8.5 pH, add 10 ml of 1.5% ammonium molybdate and about 2-3 ml of distilled water, shake well, add 1 ml of working stannous chloride and make up the volume to 50 ml with distilled water, blue colour is developed, take the OD at 660 nm wavelength on spectrophotometer within 15 minute.

$$P_2O_5 \text{ (kg/ha)} = \frac{\text{R (ppm)} \times \text{Vol. of extractant (ml)} \times \text{Volume make up (ml)} \times 2.24 \times 2.29}{\text{Wt. of soil (g)} \times \text{Aliquot taken (ml)}}$$

R= Conc. of P (ppm) from standard curve

Determination of available Potassium

Soil available potassium is determined by normal neutral 1N ammonium acetate extractant, adjusting pH 7.0 with using of flame photometer (Jackson, 1973).

Reagents: 1 N neutral ammonium acetate (7.0 pH): Dissolve 77.08 g of ammonium acetate dissolved in about 800 ml of distilled water and pH is adjusted to 7.0 with ammonium hydroxide or acetic acid and make the final volume to 1liter.

Method: Take 5 g of soil in 100 ml conical flask and add 25 ml of Ammonium acetate solution. Shake the contents on the mechanical shaker for 20-30 minutes, filter it and the make up the volume to 25 ml and determine potassium on flame photometer.

$$K_2O \text{ (kg/ha)} = \frac{\text{Conc. of K (ppm)} \times \text{vol. of extractant (ml)} \times 2.24 \times 1.21}{\text{Wt. of soil (g)}}$$

Soil organic carbon (SOC)

Material required

Conical Flask 500 ml capacity, 10 ml transfer pipette, measuring cylinder or volumetric pipette of 20 ml capacity Burette 25ml capacity

Reagents: Standard 1N potassium dichromate: 49.04 g of potassium dichromate in 1 liter distilled water, 0.5 N ferrous ammonium sulphate: Dissolve 196.1 g ammonium ferrous sulphate in 800 ml of double distilled water and add 20 ml of Concentrated Sulphuric acid slowly and cool the contents and make up the final volume to 1 liter, Concentrated sulphuric acid, Diphenylamine indicator: Dissolve 0.5 g Diphenylamine indicator in 20 ml distilled water and add 100 ml concentrated Sulphuric acid slowly, cool the reagent and store in amber bottle (To be prepared fresh), 85% ortho-phosphoric acid.

Method: Weigh 1 g or 2 g of soil passed through 0.2 mm sieve in 500 ml conical flask, add 10 ml of potassium dichromate with pipette, and shake well. Add slowly 20 ml of concentrated sulphuric acid by swirling the flask during addition. Keep the flask at room temperature for 30 minutes. Similarly prepare a blank without soil sample. When the content is cooled at room temperature, add 200 ml of distilled water and 10 ml of 85% orthophosphoric acid and shake the contents, add 10 drops of diphenylamine indicator which imparts violet colour to the contents. Titrate with 0.5 N ferrous ammonium sulphate till the colour changes from violet to bright green. At the end note the volume of the ferrous ammonium sulphate.

Volume of ferrous ammonium sulphate (FAS) used for titration of blank = A ml
Volume of ferrous ammonium sulphate (FAS) used for titration of sample = B ml
1 ml of potassium dichromate = 0.003 g of organic carbon

$$\text{Walkey- Black SOC (\%)} = \frac{(A\text{-}B) \times 0.03 \times \text{Normality of FAS} \times 100}{\text{Wt. of soil (g)}}$$

By the Walkley-black titration method having 76% recovery of soil organic carbon

$$\text{Actual SOC (\%)} = \{\text{Walkley Black SOC}\} \times (100/76) = (\text{Walkley-Black SOC} \times 1.31)$$

$$\text{SOC (g/kg)} = \text{SOC (\%)} \times 10$$

Available sulphur

Available sulphur is determined by using 0.15 per cent $CaCl_2$ solution (Williams and Steinbergs, 1959).

Reagents: 0.15% $CaCl_2.2H_2O$: 1.5 g of $CaCl_2.2H_2O$ dissolve in distilled water and make 1 liter volume, Morgan reagent: Dissolve 100 g sodium acetate in 800 ml distilled water and adjust pH 4.8 by adding 30 ml glacial acetic acid and make volume to 1 liter, Gum acacia: Dissolve 0.5 g gum acacia in 200 ml distilled water and filter the solution to get clear solution, Barium chloride: grind the barium chloride crystal to make fine powder; Volumetric flask (50 ml), pipette, burettes.

Method: Transfer 10 g soil into a 100 ml capacity plastic bottle, add 50 ml 0.15% $CaCl_2$ solution, shake it for 30 minutes on shaker, filter it through Whatman filter No.1. Transfer 20 ml aliquot in 50 ml volumetric flask, add 20 ml Morgan's reagent, 2 ml Gum acacia and 1 spoon (1.0 g) barium chloride and make up the volume. After 3-5 minutes, measure the turbidity at 410 nm.

Preparation of standards: Prepare 50 mg/l sulphur by dissolving 0.2717 g potassium sulphate (AR) in distilled water and make the volume to 1 liter

Take 0ml, 1ml, 2ml, 3 ml, 4 ml, 5 ml, 6 ml, 7 ml, 8 ml, 9 ml and 10 ml of 50 ppm sulphur in 50 ml volumetric flask, to get 0 ppm, 1 ppm, 2 ppm, 3 ppm, 4 ppm, 5 ppm 6 ppm 7 ppm, 8 ppm 9 ppm and 10 ppm sulphur standards, add 20 ml Morgan's reagent, 2 ml Gum acacia and 1 spoon (1.0 g) barium chloride and make up the volume. After 3-5 minutes measure the turbidity at 410 nm.

Calculations

$$\text{Sulphur in soil (ppm)} = \frac{\text{Conc. of S (ppm) from stand. Curve} \times \text{Volume of extactant (ml)} \times \text{Volume make up (ml)}}{\text{Wt. of soil taken (g)} \times \text{volume of aliquot taken (ml)}}$$

Determination of DTPA-extractable micronutrients

Reagents: DTPA solution: Take 13.3 ml triethanolamine, 1.967 g DTPA and 1.47 g $CaCl_2.2H_2O$, dissolved in about 500 ml of deionized water and make volume by stirring up to 900 ml. The pH of the solution is then adjusted to 7.30±0.05 by adding 4N HCl while stirring and finally the contents are diluted to one liter.

Apparatus and equipment: 1-litre volumetric flasks, 100-ml narrow mouth polyethylene bottles, pipettes, electric shaker, Whatman No.1 filter paper and atomic absorption spectrophotometer (AAS)

Method: Weigh 10 g of air-dried soil sample and transfer it to a 100-ml narrow mouth polyethylene bottle. Add 20 ml DTPA solution and put stopper. Shake on an electric shaker for 2 hours at 25 ^oC. Filter the contents through Whatman No.1 or Whatman No 42 filter paper. Also, run a blank with only DTPA solution and no soil.

Standardization: Make 1000 ppm standard stock solution for Zn, Cu, Fe, Mn from their respective salt *i.e*. $ZnSO_4.7H_2O$, $CuSO_4.5H_2O$, $FeSO_4.7H_2O$ and $MnSO_4.H_2O$. From 1000 ppm stock solution of Zn, Cu, Fe and Mn make 50 ppm working solution (Take 5 ml stock solution in 100-ml volumetric flask and make up volume with deionized water). From this 50 ppm working solution, prepare required standards solutions (below mentioned concentration in ppm) of each element in 100-ml volumetric flask by pipetting out required volume (0.0, 2.0, 4.0, 6.0, 8.0 ml for Fe; 0.0, 1.0, 2.0, 4.0, 6.0 ml for Mn; 0.0, 0.6, 1.2, 1.8, 2.4 ml for Zn; 0.0, 0.8, 1.6, 2.4, 3.2 ml for Cu) of the working standard and making the final volume with 0.005 M DTPA.

Calibrate the AAS using four standards of each element (Micro or heavy metals).

Fe: 0.0, 1.0, 2.0, 3.0 and 4.0 ppm

Mn: 0.0, 0.5, 1.0, 2.0 and 3.0 ppm

Zn: 0.0, 0.3, 0.6, 0.9 and 1.2 ppm

Cu: 0.0, 0.4, 0.8, 1.2 and 1.6 ppm

Calculation

$$\text{DTPA extractable micro or heavy metals (mg/kg)} = \frac{\text{Reading (ppm) of AAS} \times \text{vol. of DTPA solution taken}}{\text{Weight of soil (g)}}$$

$$\text{DTPA extractable micro or heavy metals (kg/ha)} = \text{DTPA extractable micro or heavy metals (mg/kg)} \times 2.24$$

Determination of Calcium Carbonate from soils

Material required: 25 ml burette and conical flask of 100 ml and 250 ml

Reagents: Hydrochloric acid standard (1 M): Add 81 ml of hydrochloric acid in about 500 ml distilled water, cool and make the volume to 1 liter, Sodium hydroxide (0.5M): Dissolve 20g of sodium hydroxide in 800 ml distilled water, cool and make the volume to 1 liter, Phenolphthalein indicator solution**,** Method: Weigh 5 g of soil sample in 250 ml conical flask and add100 ml 1 M hydrochloric acid, boil the flask for 5 minutes and cool down to room temperature or cover the flask with aluminum foil and keep overnight. Filter the contents, take 10 ml of the filtrate in 100 ml conical flask and add 2 to 3 drops of phenolphthalein indicator and titrate with 0.5 M sodium hydroxide.

% Calcium carbonate =

[(ml HCL × 1M)-(ml of NaOH ×0.5 M)]× [vol. of HCL/vol. of filtrate aliquot] × [100/(1000×2)]× [100g/wt. of soil]

Analysis of irrigation water:

Irrigation water should be collected with utmost care. The sample should not be collected from standing water, field irrigation channel, pond with stagnated water, or any contaminations like growth of algae, water used for bathing of animals etc. In order to get reliable results the time gap between collection of sample and its deposition in laboratory should be as short as possible, as the delay in giving to laboratory may result in some changes in biochemical, and physico-chemical properties.

Sample should be collected in a clean glass bottle or plastic bottle which should be rinsed atleast two to three times with sample water. In case of collection of tube well water, the tube well should run for at least 30-45 minutes before collecting the water. The sample is to be tightly corked and label giving the following information should be tied securely on the bottle.

Tag for water sampling

Collector/ farmers name, date of collection, field from where it is collected along with survey number, name of the village along with the address of the farmer. Any other water resources like canal, pond *etc.* adjacent to the source from where the water is collected. If the sample is collected from tube well, then depth of well, installation year, approximate area under irrigation may also be recorded. The collectors may record general problems such as ingress of water from nearby source of irrigation, or any effluent etc., failure of crop after irrigation, water stagnation etc.

Analysis of water

Determination of pH and the electrical conductivity

Materials Required: Glass beakers of 100 ml capacity, Distilled water, Conductivity meter, and pH meter

Standard stock solution of 0.1N KCL,

Standard buffer solutions of 4.0, 7.0 and 9.2 pH

Method: Take about 100 ml water in a glass beaker to determine EC and pH

Determination of electrical conductivity:

Standardize the conductivity meter with 0.1 N KCl solution (7.456g dry KCl in 1 liter of distilled water). Once the instrument is standardized, dip the conductivity cell in the glass beaker and take the reading. The reading observed is represented with abbreviation EC_w/dSm

Determination of pH

The pH meter is standardized with the buffers of 4.0 pH and 7.0 pH standards for two point calibration units and with 4.0, 7.0 and 9.2 pH buffer standards for three point calibration units. Once the pH meter is standardized the electrode of the pH meter is dipped in the water sample solution in the glass beaker and the reading is recorded which is represented as $pH_{w.}$ In determining EC and pH care has to be taken that the electrodes do not touch the walls or the bottom of the beaker

Determination of sodium and potassium: Procedure for estimation of Sodium and Potassium in water is same as followed in estimation of Sodium and Potassium in saturation extract of soils.

Estimation of Calcium and Magnesium in water samples: Procedure for estimation of Calcium and Magnesium in water is same as followed in estimation of Calcium and Magnesium in saturation extract of soils.

Estimation of carbonate, bicarbonate, chloride and sulphate in water samples: The same procedure will be followed as used in determination of carbonate, bicarbonate, chloride and sulphate in saturation extract of soils.

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Integrated Pest Management: Concept and Tools

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What is integrated pest management (IPM)?

According to the National Academy of Sciences (1969), IPM refers to an ecological approach in pest management in which all available necessary techniques are consolidated in a unified programme, so that population can be managed in such a manner that economic damage is avoided and adverse side effects are minimized.

Integrated Pest Management (IPM) may be defined as a system that in the context of associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains pest populations at levels below those causing economic injury (FAO, 1967).

Tools/components of IPM

Different components or tools of IPM: 1) Pest surveillance; 2) Cultural methods; 3) Mechanical methods; 4) Physical methods; 5) Biological methods (Use of parasites, predators & host plant resistance) 6) Regulatory/Legislative methods; 7) Chemical methods; 8) Behavioural methods; 9) Genetic/Biotechnological methods

Methods of pest control

Any factor that is capable of making life hard for the insect that will repel or interfere with its feeding, mating, reproduction or dispersal can be taken as a **method of insect control** in its broadest application.

They can be divided into two major categories *i.e.* (A) Natural control (B) Applied control

(A) Natural control

Under natural control the population is kept under check by the environmental resistance without the interference of man.

1. **Climatic factors:** Temperature affects insects directly; extreme hot and cold weather will kill the insects. Heavy rain has adverse effect on small insects like aphids and thrips. A high humid weather encourages the development of entomophagous fungi which check the insect population by causing disease in insects.
2. **Topographic factors:** Mountain ranges and large bodies of water act as physical barriers to the spread of insects.
3. **Natural enemies:** Every insect has a number of natural enemies like; parasites, predatory insects, predatory birds, spider, disease causing pathogens etc. They keep the insect population in check.

(B) Applied control

The control measures adopted by human agency are called applied or artificial control measures. Depending on the time of taking action the applied control measures may be

[a] Preventive or prophylactic: Action taken to prevent the occurrence or spread of infestation. Prophylactic measures are effective especially in the case of certain pests which are known to occur in an area year after year or season after season.

1. Field and plant sanitation: Regular removal of grasses and weeds will eliminate the source of infestation. *e.g.* by clipping of dried branches of citrus further multiplication of stem borer can be avoided.
2. Proper cultural methods: By using pest free healthy seeds and planting materials, possible infestation of pest can be checked. *e.g.* scales and mealy bugs in sugarcane, sweet potato weevil, banana rhizome weevil. Proper ploughing of field after harvesting of paddy and sorghum will eliminate breeding of stem borer moths in the sprouts from the stubbles.
3. Growing pest resistant varieties: Certain varieties pf crops are inherently less damaged of less infested than others by insects.
4. Seed treatment: Seed treatment protects the crop from pest. *e.g*. Imidacloprid 70 WS @ 7 g/kg of cotton seed protects cotton against leafhoppers and whiteflies.
5. Adjusting time of sowing: Avoidance of late sowing of pigeonpea checks/reduces infestation of pigeonpea pod fly. Similarly, there is less infestation of aphids in timely sown mustard compared to late sown crops.
6. Periodical raking up of manure pits to prevent breeding of rhinoceros beetles.
7. Drying: Periodical drying of harvested and stored produce prevents infestation by stored product pests.
8. Application of tar to stems or trunks of trees and to bamboo supports for preventing termite damage.
9. Application of oil over stagnant water in ponds and pools to prevent mosquito breeding.
10. By planting the crop seed deeper than usual reduces losses due to birds.

[b] Curative or remedial measures: Measures which are taken to kill the already existing pest population.

(I) Cultural methods of insect control

Cultural control is the purposeful manipulation of a cropping environment to reduce rates of pest increases and damage. Cultural management of pests involves changes -

- ✓ to make the crop less suitable for the pest
- ✓ to make it suitable for natural enemies
- ✓ to enhance the ability of the crop to withstand pest attack.

The ultimate goal is to change the agro-ecosystem in such a way that the pest population remains below EIL.

1. **Tillage:** Simply tilling a field may disrupt a pest's life cycle by causing mechanical injury, by increasing exposure to lethal temperatures, by intensifying predation by birds or small mammals, or by burying the pests deep beneath the soil surface. e.g.
   - ✓ Proper ploughing of field immediately after harvesting of paddy and sorghum will eliminate breeding of stem borer moths in the sprouts from the stubbles.
   - ✓ Ploughing the soil up to 40 cm depth expose pupae of spotted bollworm, *Helicoverpa armigera, Spodoptera litura*, rice gall midge, rice leaf roller, Gujarat hairy caterpillar, stem borers of maize *jowar*, paddy and *bajra* and adults of white grubs, eggs of grasshoppers etc. to sun rays and predatory animals.

2. **Field sanitation**: Clean cultivation is often recommended as a way to eliminate shelter and/or overwintering sites for pest populations. e.g.
   - ✓ Removing crop debris from cotton fields through allowing sheep and goats to graze cotton field after harvest, eliminates overwintering populations of pink bollworms (*Pectinophora gossypiella*).
   - ✓ By removing weeds and alternate hosts of pest population reduces.
   - ✓ Destruction of stubbles / crop residues reduces the incidence of stem borer.
   - ✓ Collection of all fallen and infested fruits of mango reduces mango fruit fly, *Bactocera dorsalis* and stone weevil, *Sternochaetus mangiferae*.
   - ✓ Destruction of attacked dead palms helps in reduction of palm weevil.
3. **Removal / destruction of alternate host:** It reduces buildup of insects in off season. Whiteflies use many broad leaf weeds as alternate host.
4. **Use of clean seed:** By using pest free healthy seeds and planting materials, possible infestation of pest can be checked. *e.g.* Scales and mealy bugs in sugarcane, sweet potato weevil, banana rhizome weevil.
5. **Selection of variety:** Grow pest resistant variety. *e.g.*

   Deccan 101 (Maize) to stem borer, Neelashan (Mango) to hoppers,
   - ✓ Bt. cotton to *Helicoverpa armigera*, ABD 101 (Tobacco) to *Spodoptera litura*, G 4 (Chilli) to thrips and mites, Pusa Purple Long (Brinjal) to FSB etc.
6. **Sowing time:** In some crops, it is possible to create discontinuity in the pest's food supply simply by altering the time of year for planting or harvesting by producing asynchrony between host plants and the pests.
   - ✓ Avoidance of late sowing of pigeonpea checks/reduces infestation of pigeonpea pod fly.
   - ✓ Similarly, there is less infestation of aphids in timely sown mustard compared to late sown crops.
   - ✓ Early planting reduces leaf folder in rice, shoot fly in sorghum and millets, white grub damage in groundnut and mustard aphids damage in *Brassica* crops.
7. **Seed rate:** Adoption of appropriate seed rate ensures proper spacing and crop canopy that helps in adoption of proper spray.
   - ✓ Use of high seed rate is recommended in those crops where removal of infested plants is helpful in minimizing the incidence of pests like, stem borer in maize, shoot fly in sorghum.
8. **Plant spacing:** Spacing modifies the micro-environment of the crop, duration of crop growth and development that influence the pest population.
   - ✓ Closer spacing increases the population of BPH and white backed plant hopper of paddy.
   - ✓ Closer spacing in cotton results in bushy growth that affects penetration of light, results in vertical growth of the plant, higher RH, hinders spraying operation that favours the higher incidence of sucking pests and bollworms.
9. **Fertilizer management:** Application of manure or fertilizers in balance amount makes plant healthy that helps to minimize the pest incidence. Application of excess nitrogenous fertilizers

increases susceptibility of crops against insect pests. However, application of potash reduces the incidence of insect pests.

- ✓ Application of potash reduces virus disease transmitted by whitefly
- ✓ Application of cakes to soil helps in keeping down the nematode population.
- ✓ Fields receiving higher dose of N-fertilizers favours incidence of the pests (BPH, yellow stem borer, whorl maggot, leaf folder, rice Hispa, green leaf hopper etc. in paddy; Pyrilla, internode borer and stalk borer in sugarcane; Bollworms, leaf folder and whitefly in cotton) than crops receiving N at low level.

10. Irrigation management

- ✓ Wireworms are controlled by flooding the field for several days or by allowing field to dry out during summer.
- ✓ Sugarcane and wheat crops can be protected from the attack of termites by frequent light irrigations.
- ✓ Cotton and brinjal crops should be frequently irrigated, as the fields receiving higher amount of water invite less oviposition by whitefly.
- ✓ Sprinkler irrigation suppresses the potato tuber moth by deterring egg laying and kills newly emerged larvae before they tunnel into the plant.

11. Plant sanitation / prunning / thinning: Plant sanitation is an essential prerequisite to reduce the insect population, to minimize the possibilities of the appearances of epiphytotics.

- ✓ Removal of deadhearts with larvae in cereals & sugarcane reduces incidence of stem borers.
- ✓ Clean cultivation reduces incidence of mango mealy bug
- ✓ Picking and destruction of damaged square & bolls of cotton reduces incidence of *Helicoverpa armigera* and *Erias* spp. in cotton.
- ✓ Picking infested shoots & fruits of brinjal reduces infestation of brinjal shoot and fruit borer, *Lucinodes orbonalis*; a damaged fruit of tomato, chilly reduces infestation of fruit borer, *Helicoverpa armigera*.
- ✓ Pruning of branches in Dec-Jan checks the incidence of citrus leaf miner, *Phyllocnistis citrella*.
- ✓ Pruning of branches in mango reduces the prevalence of leaf webber and gall insects.
- ✓ Detrashing of dry leaves from August onwards reduces the attack of pyrilla and scale insect on sugarcane crop.
- ✓ Detrashing at fifth, seventh and ninth month checks internode borer damage; and in October-November reduces stalk borer damage.
- ✓ Destruction of water shoots protects the crop from the havoc of stalk borer and internode borer.

12. Crop rotation: Growing a single crop year after year in the same field gives pest populations sufficient time to become established and build up to damaging levels. Rotating the field to a botanically different type of crop can break this cycle by starving pests that cannot adapt to a different host plant. Crop rotation schemes work because they increase the diversity of a pest's environment and create discontinuity in its food supply.

- ✓ Incidence of potato tuber moth can be reduced by suppressing cultivation of potato and tobacco crops for 2 - 3 years.
- ✓ In termite prone area, crops like; wheat, sugarcane, pigeonpea, chilli should be rotated with tobacco or onion.
- ✓ Crop rotation of same group of crops i.e. cucurbits, crucifers, graminaceous, solanaceous etc. should be discouraged to reduce population of pumpkin beetles, DBM, stem borers, *Lucinodes*, respectively.
- ✓ Rotation of groundnut with non leguminous crops reduces incidence of leaf miner.

13. **Fallowing:** Fallow can reduce pest densities by starvation. If alternate host is present fallow cannot work.

14. **Trap cropping:** Trap crops are plant stands that are grown to attract insects or other organisms so that the principal crop escapes pest attack. Protection is achieved either by preventing the pests from reaching the crop or by concentrating them in certain part of the field where they can easily be destroyed. Due to trap cropping we can keep main crop free from insecticides and this enhances natural control.
    - ✓ Growing or paired row of bold seeded mustard as a trap crop at beginning after every 25 cabbage rows reduces DBM infestation in cabbage.
    - ✓ Growing of African tall marigold cv. Golden Age as a trap crop (one row of marigold is alternated after every 16 rows of tomato) reduces tomato fruit borer, *Helicoverpa armigera* as well as leaf miner, population on tomato.
    - ✓ Tobacco nursery should be surrounded by castor (grow 15 days before seeding of tobacco) protects tobacco nursery from attack of tobacco leaf eating caterpillar, *Spodoptera litura*.
    - ✓ Tomato for DBM in cabbage.

15. **Mixed cropping /intercropping:** Intercropping lowers the overall attractiveness of the environment, as when host and non-host plants are mixed together in a single planting.
    - ✓ Tomato intercropped with cabbage (planted 30 days later than tomato) inhibits or reduces egg laying by DBM, *Plutella xylostella*.
    - ✓ Intercropping of cowpea in cotton helps in colonization of coccinellids and also enhanced the parasitism of spotted bollworm.
    - ✓ Intercropping of groundnut with pearl millet reduces the incidence of thrips, jassids and leaf miners.
    - ✓ Intercropping of *tarmaira* in *raya* reduces aphid incidence in *raya*.
    - ✓ Intercropping of redgram in cotton for cotton grey weevil; sunhemp in cucurbits for fruit fly; okra with cotton for jassids and spotted bollworm, *Erias vittella*; soybean in groundnut for leaf miner, *Aproaerema modicella*; cowpea / onion / soybean in cotton for thrips aphids and jassids.

16. **Hedge rows and refuge line:** Hedgerows provide benefits to enhance natural enemies. Non cropped refugia can be used to harbour beneficial organisms, especially insects and spiders. Refuge line is also useful in resistance management.

17. **Strip harvesting:** It is similar to trap cropping. Crops can be harvested in alternate strip so that insect may not move in main crop.

18. **Modify harvest schedule:** By adjusting time of harvesting, a crop can be saved from attack of the pest.
    - ✓ Cotton should be picked as soon as the bolls open to avoid attack of dusky cotton bug, *Oxycarenus* sp.
    - ✓ Sugarcane should be harvested before mid-February, when moth of top borer appears on wings. If it is not possible, the terminal portion should be cut and fed to cattle.
    - ✓ Maize borer, *Chilo partellus* hibernates in the stalks, so do not keep maize for fodder in field but harvest the crop and chopping up before emergence of moth.
    - ✓ Infestation of Sweet potato weevil reduces in timely harvest of sweet potato.
19. **Ratooning:** Avoiding rationing of pigeonpea during off season helps in reducing the carryover of pod fly and eriophyiid mite, *Aceria cajani*

(II) Mechanical methods of insect control

Use of mechanical devices or manual forces for destruction or exclusion of pests. It includes killing or trapping pests by mechanical means or the use of barriers to prevent pests from gaining access to plants, stored products or other materials.

Manual force

1) **Hand picking of the egg masses, caterpillars *etc*.:** In the field, insects at different stages can be picked if they are easily accessible to the picker.
    - ✓ Collection and destruction of damaged square & boll with larvae of *Helicoverpa armigera* and spotted bollworm in cotton.
    - ✓ Egg masses of rice stem borer, red hairy caterpillar, *Spodoptera litura*,
    - ✓ Collection of larvae and pupae of lemon butterfly
    - ✓ Grubs of mustard sawfly, *Athalia lugens proxima.*
    - ✓ Developmental stages of Epilacna beetle on brinjal, cucurbits and potato.
2) **Using hand nets**
    - ✓ Collection of grasshoppers, earhead bugs, fruit sucking moths *etc.* with hand nets.
3) **Beating: preparatory**
    - ✓ Swatting housefly and mosquito.
    - ✓ Killing locusts with thorny bushes.
4) **Sieving and winnowing:** These are commonly employed against insect pests of stored grains.
    - ✓ Red flour beetle, *Tribolium castaneum* (sieving); rice weevil, *Sitophilus oryzae* (winnowing)
5) **Shaking the plants**
    - ✓ Passing rope across rice field to dislodge caseworm over standing water that is then drained out to collect the pest and suppress the population.
    - ✓ Shaking neem tree to dislodge white grub's beetles
    - ✓ *Helicoverpa* larvae on redgram can be collected by shaking the infested plant.

6) **Hooking**

- ✓ Iron hook is used against adult rhinoceros beetle to pick out of the hole.
- ✓ Removal of grubs of stem borer in mango and cashew.

7) **Crushing and swatting:** By hitting and crushing the cockroaches, bed bugs and lice like insects can be managed.

8) **Combing:** Delousing method for Head louse

9) **Shooting:** Shooting is relevant for noninsect pests like; fox, monkey, pig, deer, ground squirrels and bird etc. It is **restricted under prohibitory laws** for certain animals in India.

10) **Brushing and sweeping**

- ✓ Woolen fabrics for clothes moth, carper beetle.
- ✓ Storage pests, blood sucking insects of domestic animals, scale insects/mealy bugs on rose etc. can be reduced by brushing and sweeping techniques.

Mechanical force

a) **Entoleter:** Centrifugal force - breaks infested kernels - kill insect stages - whole grains unaffected - useful for storage pests.

b) **Hopper dozer**: Kill nymphs of locusts by hording into trenches and filled with soil.

c) **Tillage implements**: Soil borne insects, red hairy caterpillar.

d) **Erection of bird perches:** Attracts insectivorous birds. This is useful in management of *H. armigera* in gram, pigeonpea etc.

e) **Mechanical traps**

- ✓ Rat traps of various shapes like box trap, wonder trap, glue trap wire trap, snap trap etc. are helpful in trapping different rat species.
- ✓ Heaps of plants/grasses/weeds traps red hairy caterpillar in groundnut, *Spodoptera litura* in cotton and Giant African snail, *Achatina fulica* and collect and kill the trapped pests.
- ✓ Placing cut pieces of pith of coconut fronds for attracting red palm weevil, *Rhynchophorus ferrugineus*.
- ✓ Placing cut piece of banana pseudostem to attract banana pseudo stem weevil, *Odoiporus longicollis*.
- ✓ Use of methyl eugenol attracts fruit fly, *Bactrocera* sp.

f) **Use of sticky traps:** Yellow sticky trap can be used for whitefly, aphids, thrips.

g) **Sex Pheromone trap**: Synthetic sex pheromones are placed in traps to attract males. e.g. *Helicoverpa armigera*, *Spodoptera* litura, *Plutella xylostella*, *Leucinodes orbonalis etc.*

h) **Air suction traps:** This trap is fixed in Godowns against stored grain pests.

Mechanical exclusion

i) **Mechanical barriers:** Mechanical barriers prevent access of pests to hosts.

1. **Wrapping the fruits:** Covering individual fruits with brown paper bag against pomegranate fruit borer, *Deudorix isocrates* and citrus fruit sucking moths, *Eudocima* sp.

2. **Banding**
   - ✓ Banding (15 cm wide) with grease or slippery polythene sheets (alkathene) around trunk of mango - Mango mealy bug.
   - ✓ Sticky bands around the tree trunk are useful against red ants, *Oecophylla smaragdina*.
3. **Netting:** Putting screens on windows, doors and ventilators of house and green house provides protection against house flies, mosquitoes, etc, in house and vector in green house.
4. **Trenching:** Digging trenches around the field helps to prevent movement of larvae from one field to another.
   - ✓ Trapping of larval march of red hairy caterpillar, *Amsacta albistriga*; armyworm, *Spodoptera mauritiana*; crawlers of locust, *Schistocera gregaria* and tobacco leaf eating caterpillar, *Spodoptera litura*.
5. **Sand barrier:** Protecting stored grains with a layer of sand on the top.
6. **Water barrier:** Ant pans for ant control.
7. **Tin barrier:** Coconut / Date palm / Oil palm trees protected with tin band / *Prosophis* thorns to prevent rat damage.
8. **Electric fencing**: Low voltage electric fences against noninsect pests like rats and jackals.
9. **Paper and collar barriers:** Paper and collars are placed around small plants like tobacco and potato to protect them from cutworm infestation.
10. **Packaging:** Insects can enter packages through seams or directly through packing materials. Several stored-product pests that can bore into packaging are *Rhyzopertha dominica*; *Lasidoerma serricorne*; the warehouse beetle, *Trogoderma variable;* the rice moth, *Corcyra cephalonica* etc. The polymer films, laminations, and extrusions can protect packages from insect infestations, whereas polyester, polyurethane, or polypropylene films resist insect penetration. Bags lined with alkathene films afford sufficient protection against stored grain pests.
11. **Wire-gauge screens or nylon meshes/nets:** It is used to cover seedbeds, vine yards, mango trunks to prevent the damage by insects like defoliators, borers and leaf miners.
12. Crushed eggshells or hydrated lime spread around plants will discourage slugs.

j) Clipping

- ✓ Clipping of leaf tips of rice seedlings containing egg masses of yellow stem borer reduces the carryover of the infestation from seedbed to main field.
- ✓ Removal of terminal parts of cotton reduces eggs of *Helicoverpa armiger* and *Erias* spp.

k) Burning / fire / flaming: Burning of rat, locust and grasshopper through flame thrower. Burning torch against hairy caterpillars.

l) Use of reflecto-ribbon: Due to reflection grainvorous birds remains away from field of bajara, sorghum, maize etc.

Appliances in controlling the pests

1. **Light traps:** Most adult insects are attracted towards light in night. This principle is used to attract the insect and trapped in a mechanical device. Nowadays Ultra Violet light is widely used in light trap. Attraction of insects through light is physical principle but attracted / trapped insects kills through mechanical devices.

2. **Pheromone trap**: Synthetic sex pheromones are placed in traps to attract males. The rubberized septa, containing the pheromone lure are kept in traps designed especially for this purpose and used in insect monitoring / mass trapping programme.
3. **Yellow sticky trap:** Cotton whitefly, aphids, thrips etc. are attracted to yellow colour and trapped on the sticky material.
4. **Bait trap:** Attractants placed in traps are used to attract the insect and kill them. *e.g.* Fishmeal trap**:** This trap is used against sorghum shoot fly.
5. **Pitfall trap**: It helps to trap insects moving about on the soil surface, such as ground beetles, Collembola, spiders.
6. **Probe trap:** Probe trap is used by keeping them under grain surface to trap stored product insect.

(III) Physical methods of insect control

It involves modification of some physical features of environment to render it unsuitable to a pest to minimize (or) prevent pest problems.

1. Manipulation of temperature: Extreme of temperature can cause death of any pest

Application of heat

- ✓ Sun drying the seeds to kill the eggs of stored product pests.
- ✓ Hot water treatment (50 - 55ºC for 15 min) against rice white tip nematode. Similarly, hot water treatment is also useful in managing sugarcane scale insect.

Solarization

- ✓ Solarization can result in temperature between 50 to 60 ºC in the top few inches of soil that kills dormant stages of different pests.

Application of cold

- ✓ Cold storage of fruits and vegetables to kill fruit flies (1 - 2°C for 12 - 20 days).

2. Manipulation of moisture

Flooding

- ✓ Alternate drying and wetting rice fields against BPH.
- ✓ Drying grains (below 8-10% moisture level) prevents insect damage by stored grain pests.
- ✓ Flooding the field for the control of cutworms, armyworm, white grubs, termites etc.

Draining

- ✓ Draining of water from paddy field for 3-5 day is useful to control infestation of BPH and whorl maggot in paddy.
- ✓ Draining out water is used to reduce the paddy case worm, *Paraponyx stagnalis*.

3. Use of light

- ✓ Treating the grains for storage using IR light to kill all stages of insects e.g. Infra-red seed treatment unit.
- ✓ Providing light in storage godowns as the lighting reduces the fertility of Indian meal moth, *Plodia interpunctella*.

- ✓ Light trapping: It is useful for monitoring of insect pests in an area.

4. Manipulation of air

- ✓ Increasing the CO_2 concentration in controlled atmosphere of stored grains to cause asphyxiation in stored product pests.
- ✓ Pouring kerosene in rice fields to arrest the spread of rice case worm, *Paraponyx stagnalis*
- ✓ Spreading kerosene layer on drains to kill mosquito larvae is in practice.

5. Use of irradiation

- ✓ Gamma irradiation from Co-60 is used to sterilize the insects in laboratory which compete with the fertile males for mating when released in natural condition.

6. Use of abrasive dusts

- ✓ Red earth treatment to redgram: Injury to the insect wax layer.
- ✓ Activated kaolinite clay: Injury to the wax layer resulting in loss of moisture in leading to death of stored grain pests. It is used against stored product pests.
- ✓ Drie-Die: This is a porous finely divided silica gel used against storage insects.
- ✓ Applying ash over aphid infested plant parts reduce its incidence.

7. Use of sound: By producing sound waves some insects/birds/rodents can be influenced.

- ✓ Ultrsonic sound waves can be used against nocturnal insects like mosquitoes and cockroaches.
- ✓ Birds and rodents that thrive on grains can be scared by producing sounds.

8. Increase concentration of CO_2: stored pests get killed due to asphyxiation.

9. Producing alarming signals: By producing dreadful sounds of bird's enemies, birds may go away from that area.

10. Use of frightening devices: eg. Birds

11. Turning of Grains: It is the process of moving grain by transferring the contents of a silo to a nearby empty one. The result is a break-up of pockets of insect infestation, a slight loss of heat to the atmosphere, an averaging out of temperature and hence a reduction in maximum temperature and the mixing of any moist grain with the rest of the bulk. However, moisture content of the bulk of the grain is not lowered appreciably by turning.

(IV) Legislative methods of insect control

Definition: Legislative control involves the enactment of laws to regulate the entry, establishment and spread of foreign plant and animal pest in a country or area and eradication or suppression of the pests established in a limited area.

Pests accidentally introduced into India

1. Pink bollworm - *Pectinophora gossypiella*
2. Cottony cushion scale - *Icerya purchasi*
3. Wooly aphid of apple - *Aphelinus mali*
4. San Jose scale - *Quadraspidiotus perniciosus*

5. Potato tuber moth - *Gnorimoschima operculella*
6. Spiraling whitefly - *Aleyrodicus dispersus*
7. Cyst (Golden) nematode of potato - *Globodera* sp.

Foreign pests from which India is free

Mediterranean fruit fly - *Ceratitis capitata*

Cotton boll weevil - *Anthonomos grandis*

Codling moth of apple - *Lasperysia pomonella*

(V) Biological methods of insect control

Biological control: definition

The study and utilization of parasitoids, predators and pathogens for the regulation of pest population densities. Biological control can also be defined as the utilization of natural enemies to reduce the damage caused by noxious organisms to tolerable levels.

Successful biocontrol examples

1898 - A coccinellid beetle, ***Cryptolaemus montrouzieri*** was imported into India from Australia and released against **coffee green scale**, ***Cocus viridis.*** Even today it is effective against mealybugs in South India.

1920 - A parasitoid ***Aphelinus mali*** introduced from England into at Saharanpur (Uttar Pradesh, India) to control Woolly aphid on Apple, ***Eriosoma lanigerum*.**

1926 - The coccinellid beetle, *Rodolia cardinalis* (Origin: Australia), for cottony cushion scale, *Icerya purchasi* was introduced to India via USA (California).

Parasitoids of agricultural importance

Parasitoids	**Pests**
Egg parasitoid	
Trichogramma chilonis	Eggs of sugarcane internode borer, Cotton bollworm, rice leaf folder
T. japonicum	Eggs of rice stem borer
Telenomus rowani	Eggs of rice stem borer
T. remus	Eggs of tobacco caterpillar
Egg - larval parasitoid	
Chelonus blackburni.	Eggs of cotton spotted bollworm
Larval parasitoid	
Bracon hebetor *B. brevicornis* *Goniozus nephanitidis*	Coconut black headed caterpillar
Larval - Pupal parasitoid	
Isotima javensis	Top shoot borer of sugarcane
Pupal parasitoid	
Brachymeria nephantidis *Trichospilus pupivora*	Pupae of coconut black headed caterpillar

Nymphal and adult parasitoid *Aphelinus mali* *Encarsia formosa* **Lepidoptera** *Epiricania melanoleuca*	 Aphids Cotton whitefly Sugarcane Pyrilla

Predators of Agricultural Importance

Order /Family	Predator	Pest
Odonata	Dragon fly, Damsel fly	Midges, Moths
Dictyoptera	Preying mantids	Caterpillars
Hemiptera Reduviidae Pentatomidae Belostomatidae Miridae	 Assassin bug Stink bugs Giant water bug Mirid bug	 Red cotton bugs Red hairy caterpillars Aquatic insects BPH
Chrysopidae	Green lace wing	Aphids, psyllids, coccids, mites
Coleoptera Coccinellidae Staphylinidae	 Coccinellids Rove beetle *Stethorus*	 Aphids, psyllids, coccids, mites Rice leaf folder Sugarcane mites
Lepidoptera	*Epiricania melanoleuca Dypha*	Sugarcane pyrilla Sugarcane wooly aphid

Microbial control

Microbial control: Microbial control refers to the exploitation of disease causing organisms to reduce the pest population below the economic damage level.

Microbial insecticides: Microbial insecticides are products containing microorganisms (or their byproducts) which result in insect diseases

1. **Viral pathogens**

   Baculoviruses

   NPV: - *Helicoverpa*, 250-500 LE/ ha HaNPV

   - *Spodoptera*, 450 LE/ ha / 2.5 x 10^{11} POB/ ml

   GV (Granulosis Virus): - for Indian meal moth

2. **Fungal pathogens**

   Beauveria- Boverin

   Metarhizium- Bio- 1020

3. **Bacterial pathogens:**

   Bacillus thuringinesis- Btk.

(VI) Chemical control

(A) Insecticides of plant origin (Botanical insecticides): Insecticide which is developing from the plants is called botanical insecticides or insecticides of plant origin. Plants are known to produce a diverse range of chemicals that protect the plants from insect pests. Some of the important plant that used for development of insecticides is (1) Neem, (2) Nicotine Sulphate, (3) Pyrethrum, (4) Rotenone, (5) Custard apple, (6) Pongram

1) Neem (*Azadiracta indica*)

- ✓ It is indigenous to India.
- ✓ All the parts of the neem trees possess insecticidal activity but seed kernel is the most effective.
- ✓ **Azadiractin** has been found in neem tree and it shown repellent, antifeedant and insecticidal activity against a number of insect pests.
- ✓ The repellent and antifeedant effects of neem have been reported againstchewing and bitting type and sucking insects.

2) Nicotine sulphate

- ✓ Nicotine or nicotine sulphate extracted from the *Nicotiana tebacum* or *N. rustica*,
- ✓ Nicotine sulphate is much less toxic to warm blooded animals and quite stable.
- ✓ If soap is added to it at the time of spraying, nicotine is liberated more quickly it more effective.

3) Pyrethrum

- ✓ It is available in the flowers of *Chrysenthemum cinararaiefolium.*
- ✓ The toxic substances present in pyrethrum are phyrethrin and Jasmolin.
- ✓ It is toxic to most insects and acts as a contact poison.
- ✓ It is relatively harmful to mammals and has no phytotoxic effect.

4) Rotenone:

- ✓ The *Derris* plant has been used to get rotenone.
- ✓ The roots of *Derris* species has been used for the commercial production of rotenone.

5) Custard apple:

- ✓ Powdered seeds of custard apple applied to rice and wheat grains have been reported to provide protection against storage insects.

6) Pongram or karanja:

- ✓ Karanj oil as a surface protectant effecting checked infestation by storage pests.
- ✓ The plant extracts act as feeding deterrent against Gujarat hairy caterpillar, *Spodoptera litura*

(B) Synthetic insecticides: Cyclodiens, Organophosphates, Carbamates, Synthetic Pyrethroids, Neonicotinoids groups of insecticides

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