11.6 Management Practices for Sustainable Agriculture

1. Sustainable Utilization of Land Resources

Land is a nonrenewable natural resource comprising of three vital components namely soil, water and vegetation. Soil degradation is posing a potential threat to ecological balance and sustainability of livelihood systems of people due to indiscriminate use of land, water etc.

Soil degradation

Soil degradation is a process that lowers the current and future capacity of soil to support the human life. This degradation may by induced phenomena by human as well. Similarly FAO (1979) defined soil degradation is a phenomena that reduced the potential capacity of soil to quantitative or qualitative produce of crops.

Causes of degradation

i. Vegetable removal when clean the land for agriculture operations

ii. Removal of cover especially for fuel, fencing and weed etc.

iii. Livestock grazing caused reduction in vegetable cove along with soil tamping

iv. Agricultural activities like cultivation in steep slopes, farming without soil conservation measures, improper irrigation and use of heavy machinery, and Contour and terrace faring without proper management especially irrigation

v. Use of heavy machinery

vi. Soil Pollution with the discharge of and misuse of agrochemical

Kinds of degradation

1. Physical

a) Compaction and crusting

b) Desertification

c) Erosion and depletion

d) Wind erosion

e) Water erosion

2. Chemical

a) Fertility imbalance

b) Elemental

c) Acidification

d) Sodification

e) Toxic compounds

3. Biological

a) Organic matter reduction

b) Decline in macro and micro-fauna

1. Management of Physical Degradation

Among the physical degradation processes, soil erosion is the major process responsible for soil degradation. Water erosion is relatively more important in semiarid regions and wind erosion in arid regions. Recommended soil conservation measures are:

a. Water Erosion

Agronomic measures

i. Preference to erosion resistant crops such as legumes and other ground smothering crops,

ii. Tillage practices to improve water intake into the soil and reduce surface runoff,

iii. Counter cultivation (ploughing, sowing and inter cultivation across the slop)

iv. Strip cropping of erosion resisting and erosion permitting grain crops,

v. Application of heavy dose of bulky organic manures including mulching.

Mechanical Measures

i. Contour bunds and graded bunds,

ii. Bench terraces,

iii. Contour trenching,

iv. Gully control,

v. Grassed water ways, and

vi. Watershed approach

Forestry Measures

i. Establishing perennial trees and grasses,

ii. Agroforestry

b. Wind erosion

i. Minimum tillage with rough soil surface to prevent wind erosion,

ii. Stubble mulching,

iii. Cover crops,

iv. Mulching and

v. Wind breaks and shelterbelts

c. Compaction, Crusting and Sealing

Compaction is usually caused by the use of heavy farm machinery. Crusting and sealing however, results from the impact of rain drops if the soil is not well protected. Soil compaction and sealing inhibit water infiltration into the soil and exchange of gasses between the soil and atmosphere. Small seeded crops, grasses and vegetables are particularly sensitive to soil crusting.

Measures to minimize the adverse effect include:

i. Addition of large quantities of bulky organic manures to improve soil aggregation,

ii. Adverse effect of soil crusting, immediately after seeding, can be minimized considerably by dragging, a heavy thorny branch over the soil surface or by working a light spike tooth harrow over the soil surface without disturbing the germinating seed,

iii. If water is available, a light irrigation can overcome the crust problem leading to optimum seed germination, and

iv. Application of sand to improve physical conditions for increasing water infiltration into the soil.

2. Management of chemical degradation

Amelioration of salt affected soils

These are broadly grouped into three:

a) Physical and hydro-technical amelioration

Management options include:

i. Deep ploughing improve the water infiltration into the soil,

ii. Sand mixing (up to 50 t ha^{-1}) to improve air and water absorption,

iii. Profile inversion of sub-surface soil horizons contain gypsum,

iv. Leaching with good quality water and draining the profile to remove excess soluble salts constitutes hydrothermal processes of physical amelioration.

b) Chemical Amelioration

i. Soluble calcium salts such as $CaCl_2$ or gypsum

ii. Acidifying materials like sulphur, iron sulphate, sulphuric acid etc. for solubilizing insoluble native soil calcium and

iii. Waste materials such as phospho gypsum etc.

c) Biological Amelioration

i. Biological activity can be stimulated by simply allowing a grass cover to develop, through forestation or by adding organic material,

ii. Addition of bulky organic manures/organic materials improves water infiltration and release of carbon dioxide during decomposition,

iii. In calcareous soils, the carbon dioxide brings in the soluble calcium for exchange to replace sodium in the soil exchange complex,

iv. Barley and wheat crop appears to be a reasonably good choice for sodic soils during rabi. For kharif, pearl millet considered as possible alternative to rice. Native grasses *Cynodon dactylon* and *Panicum antidotale* have remarkable potential for establishment and growth in sodic soils,

v. Rice based cropping systems are more suitable and promising than other systems on such types of soils. Wheat-rice or berseem-rice for 3 years and diversification of cropping system afterwards is ideal. Inclusion of a green manure crop in the system leads to sustainable production under several situations,

vi. Aged seedlings for transplantation with 4to 5 seedlings per hill appear optimum for adequate stand establishment of rice,

vii. In general, around 20% higher dose of fertilizer than the recommended leads to near optimum yields.

Amelioration of acid soils

i. Rice should be the major crop of acid soils as it has greater degree of tolerance to acidity,

ii. Application of lime

iii. Legumes, cotton, maize, sorghum, wheat and linseed respond to lime application, and

iv. Tree species such as sesbania is also affective.

Amelioration of Water Logged Soils

i. Planting should be done on mounds so that crop escapes complete submergence,

ii. Fertilizers should be applied along with planting,

iii. Protect the seedlings from termites,

iv. Land grading to maximize water infiltration into the soil and to minimize surface accumulating in low laying areas,

v. Provision of an effective open drainage system to divert runoff entering the low-laying areas, and

vi. Rice may be preferred for water logged soils.

3. Management of Biological Degradation

Decline in soil organic matter is largely attributed to:

- Intensive cultivation, which stimulate decomposition of soil organic matter,

- Excessive dependence on inorganic fertilizers and neglect of adequate input of FYM and other bulky organic manures,
- Cropping systems aimed at yield advantage and neglect of soil organic matter build up, and
- Arid and semiarid climates

Built-up of Organic Matter in Soil

i. Forest systems add larger and more amount of organic matter to the soil than grass land systems, which in turn, provide greater amounts than crop production systems,

ii. Green manures

iii. Crop residues

iv. F.Y.M

v. Poultry manure

Reduction in soil macro and micro fauna

Biological processes are central to soil fertility and productivity and sustainability of agro-ecosystem. The number of organisms varies greatly depending on moisture contents, physical condition of soil, temperature, food supply and soil reaction.

Major practices influencing the soil organisms are:

i. Tillage practices such as deep and excessive ploughing leads to organic matter loss and which leads to reduction in soil organism population. Change in soil physical properties due to puddling has similar adverse effect on soil organisms.

ii. Cropping systems such as cereal-cereal or non-legume-non legume results in reduced population of soil organisms.

iii. Continuous use of inorganic fertilizers without regular addition of bulky organic manures suppresses their activity.

iv. Plant protection chemicals may temporarily inhibit the activity of soil microbes.

Population and activity of soil organisms can be increased by:

i. By following legume-cereal cropping system.

ii. Bulky organic manures and green manures aid soil organisms build up due to improvement in soil organic matter.

iii. Agroforestry and organic farming systems create ideal soil conditions for multiplication and activity of soil organisms.

Soil quality

Definitions

- Soil quality or soil health is "**the fitness of soil for use**"
- Soil quality means, managing soil for today and tomorrow.
- To a production agriculturist it means- productive land that is enhancing or sustaining crop productivity, increase the profits and/or preserve the soil reserve for future.

Management options for soil quality

To increase the soil quality the uses of conservation practices which improve soil function are of immense importance. Options include rotations of crops and growing of cover crops. These can increase organic matter of soil, nitrogen contents and reduced the soil erosion. Further, practices that can reduce disturbance (avoid excess tillage), increase crop diversity, ground cover, addition of organic matter and can cycle water, nutrients and energy efficiently, also helpful in increasing soil quality. Use of composting and other organic materials is an effective way to stabilize nutrient status. Due to primary decomposition, quality of compost is much better when compared with its raw components. However, its contribution is lower than that of sticky gums and waxes of soil particles aggregate because these substances are also released at initial decomposition. Similar to manure, soil application of compost has not any burning effect on plants or plant roots. Humates and humic acid and its derivatives, obtained from oxidized soil, sugar, gums, waxes have important role in soil microbiology and structure. These derivatives are not considered as humus. It is necessary to add enough quantity of organic matter to soil as small quantity will not convert into the humus. During decomposition, small amount of organic matter convert in to carbon dioxide. Tillage smoothes the soil surface and destroys natural soil aggregations and earthworm channels. Porosity and water infiltration decreases following most tillage operations. Any tillage system that leaves an excess of 30% surface residue is considered a "conservation tillage" system by USDA. Conservation tillage includes no-till, zero-till, ridge-till, zone till and some variations of chisel plowing and disking. The principal benefits of conservation tillage are reduced soil erosion and improved water retention in the soil, resulting in more soil resistance. Additional benefits that many conservation tillage systems provide include reduced fuel consumption, flexibility in planting and harvesting, reduced labor requirements and improved soil tilth.

Two of the most common conservation tillage systems are ridge tillage and no-till. Ridge tillage is a form of conservation tillage that utilizes specialized planters and cultivators to maintain permanent ridges on which row crops are grown. After harvest, crop residue is left until planting time. To plant the next crop, the planter places the seed in the top of the ridge after pushing residue out of the way and slicing off the surface of the ridge. Ridges are reformed during the last cultivation of the crop. Often, a band of herbicide is applied to the ridge top during planting. Conventional no-till methods have been criticized for a heavy reliance on chemical herbicides for weed control. Additionally no-till farming requires careful management and expensive machinery for some applications. In many cases spring temperature of the untilled soil is lower than that of tilled soil. This lower temperature can slow germination of early planted corn or delay planting dates. Also, increased insect and rodent pest problems have been reported. On the positive side, no-till methods offer excellent soil erosion prevention and decreased strips across the field.

2. SUSTAINABLE UTILIZATION OF AGRO-BIODIVERSITY

Agro-biodiversity means the genetic variability among plants, animals, fish, insects, and microbes (fungi, bacteria and viruses). It helps farmers in producing range of agricultural products while keeping farm health and sustainability. Agro-biodiversity has following key benefits:

1. High yields and profits through diversified products

2. Keeping stability and sustainability of agricultural resources

3. Soil and water conservation

4. Preserving the structure of the ecosystem and the maintenance of species diversity

5. Environmentally friendly management of weeds, insect-pests and diseases

6. Less dependence on off-farm inputs

7. Decreased agricultural pressure on natural lands and forests

8. Providing multi-source human nutrition

How biodiversity on the farm can be maximized?

1. Integration of animal husbandry and crop production

2. Maintaining permanent hedgerows, cover crops, trees and water pools

3. Replacing mono-cropping with multi-cropping, inter-cropping and crop rotations

4. Pasture management with broad range of forage crops

5. Avoiding fallowing by growing off-season cover crops

3. INTEGRATED NUTRIENT MANAGEMENT

Integrated nutrient management (INM) is the practice of maintaining soil fertility through utilization of all possible sources of nutrient supply (organic manures, composts, bio-fertilizers and inorganic fertilizers) by using them in integrated manner. It draws following benefits:

1. It keeps in equilibrium the readily available, slowly available and fixed forms of nutrients.

2. Physical, biological and chemical health of soil is maintained.

3. It maintains continuous nutrient supply to crops in terms of time and space by synchronizing plant demand with soil and applied nutrient pools.

4. Minimize nutrient losses and avoids soil and water pollution by fertilizers.

Major components of INM:

1. Organic Manures:

a) In-situ organic manuring

This is the soil manuring at site. It has 2 sources:

i. In-situ animal manuring

Usually practiced in areas where cattle, sheep buffalos, and goats are reared in the open lands and later on their dung is ploughed down into the soil.

ii. In-situ plant manuring (green manuring)

It is the growing of green manure crops (guara, dhaincha, berseem, sunhemp, and senji) then incorporating them into soil at the time of flower initiation.

b) Ex-situ organic manuring

Plant and animal wastes from agriculture and agro-industrial sources such as:

i. Livestock and human waste

ii. Crop residues, tree waste

On an average, crop residues contain about 1.5% K_2O, 0.6% P_2O_5, and 0.5% N.

iii. Urban and rural wastes

- Urban and rural composts
- sewage and sludge

Rural and urban waste on an average contains about 0.8-1.2% K_2O, 0.5-1.0% N, and 0.4-0.8% P_2O_5.

iv. Agro-industries by products

- Wheat and rice mills waste
- Bagasse and press mud
- Saw dust

2. VERMI-COMPOST:

Vermi-composting is a process where worms are used in transforming agricultural and kitchen waste, and city garbage into valuable fertilizer products. Usually, vermicompost contains 0.4-0.9% N, 0.2-0.3% P_2O_5 and 0.2-0.5% K_2O, and lot of micronutrients.

There are following advantages of using vermicompost:

1. It improves soil fertility as well as physico-biochemical properties of soil.

2. It adds considerable amounts of micronutrients to soil.

3. Rich in growth promoters and enzymes.

5. Maintains soil pH to neutral range thus helps in keeping nutrient availability.

6. Quality, shelf life and nutritive value of horticultural crops is enhanced.

7. Al toxicity is reduced.

3. Biofertilizers:

Biofertilizers are the microbial rich organic materials manufactured to get benefits from a number of biological processes such as biological N fixation, nutrient solubilization, growth promoting hormones carried out by living micro-organisms.

Kinds of biofertilizers

a) Nitrogen Fixing Biofertilizers

These biofertilizers contain nitrogen fixing bacteria and blue green algae that add plant available N to the soil by after fixing atmospheric nitrogen.

i. Rhizobium

Rhizobium is specific to crop and used for inoculation purpose in legumes crops. Rhizobium bacteria fix atmospheric nitrogen in especially in legumes, however in some non-legumes it also fix atmospheric nitrogen. Act on pulses like mash, moong, arhar, pea, lentil, chickpea and others like soybean, groundnut, berseem, and lucerne etc. Rhizobium can fix 50-150 kg N/ha/season and increase yield 10-30%. It is needed in areas where a particular legume crop has not grown earlier or is being grown after 3-4 years. Twenty grams of culture is required to inoculate 1 kg seed of pulse crop. Crop inoculation groups along with their rhizobium species and legume crops have been listed in Table 11.2.

Table 11.2.: Major cross inoculation groups with inoculants and host plant

Cross inoculation group	Rhizobium species	Legume host
Pea group	*R. leguminosorum*	pea, sweet pea
Alfalfa	*R. meliloti*	sweet clover
Clovers	*R. trifoli*	clover/berseem
Bean group	*R. phaseoli*	all beans
Soybean group	*R. japonicum*	/soybean
Lupine group	*R. lupini*	lupins
Cow pea group	*R. species*	cowpea, gram, arhar, urd, moong, groundnut

ii. Azotobacter

Azotobacter is non- symbiotic, free living and aerobic nitrogen fixing bacteria mostly used on a limited scale found in close association with vegetable crops. Besides vegetables it is also effective for sugarcane, cotton, cereals and millets. It can fix about 15-25 kg N/ha/season and causes about 10-15% increase in yield. Azotobactor is reported to synthesize growth promoting substances like IAA, IBA, NAA, cytokinins , and GA, B-vitamins which help in plant growth promotion. Azotobactor synthesizes antibiotic substances which has effective control against various fungal infections that are caused by Alternaria & Fusarium, viral and bacterial diseases of crop plants. It mineralizes tricalcium phosphate and thus increases uptake of P in plant. It has been reported that in rice and wheat yields were increased by 5-31 and 16-30%, respectively with azotobacter culture. This can be applied in the fields either by seed inoculation, seedling inoculation, pelleted seeds, pre-inoculated seed or granular soil inoculants. Of these, seed and seedling inoculation are common, effective and easy. In seed inoculation, carrier based culture as per need and it is mixed with water of 500 mL/packet to form slurry adding 10% sugar and 40 percent gum arabica. Required quantity of seed is then mixed with slurry to form uniform coating of seed with inoculants. Two kilograms of the culture is mixed with 25 kg FYM and broadcasted in the field uniformly before sowing. The roots of seedlings can be dipped in azotobacter slurry prior to transplantation.

iii. Azospirillum

This species is also crop specific and commonly useful for cereal. The crops responding to azospirillum are maize, barley, wheat, rice, oats, sorghum, pearl millet and forages. Roots of these crops excrete organic substances (exudates) which are good source of carbon and energy for azospirillum and stimulate its multiplication. It can enhance crop yield by 14-20%. It can fix about 20-25 kg N/ha/season. Application procedure is same as for azotobacter**.**

iv. Blue-green algae

These are cyanobacteria, free-living organisms. They are photosynthetic nitrogen fixers (they use energy derived from photosynthesis to fix atmospheric N). The BGA anabaena inhabits cavities in the leaves of floating fern Azolla and fix nitrogen in lowland rice. The Azolla-anabaena complex is a significant non symbiotic system without nodule formation. The common Azolla specie is *Azolla pinnata*. The BGA can be cultured in small pits and used as an inoculum in rice fields at 12 to 15 kg ha^{-1} or mass multiplied in cropped area assimilated into the soil before planting.

BGA boosts rice production (up to 50 %) under an-aerobic conditions by fixing nitrogen and release of plant growth regulators for crop. They are reported to fix 20-25 kg N/ha/season. It can improve texture of soil by increasing organic contents and amino acids, produces organic acids that solubilize P precipitates, Ca which ameliorate soil, growth promoting substances, vitamins for rice and oxygenates the field impounded water to prevent accumulation of reduced iron and sulphates which are injurious to root growth. Blue green algae conserve nitrogen and carbon and converting the sodium clay into calcium clay. Under laboratory conditions about 12-34% decrease in soil salinity through mat has been reported (*Anabaena torulasa*). BGA produce the compounds responsible for "Earthy" odors detected in soil. Some BGA secrete mucilaginous substances which bind soil particles into soil aggregates.

v. Azolla

Azolla is applied in rice field at the rate of 7.5 kg/ha as a green manure. It is allowed to grow in flooded conditions for 2-3 weeks before transplanting, after that water is allowed to drain and azolla is mixed with cultivation in the field. As a double crop 10-50 q/ha of azolla (hybrid azolla at 60 kg/ha) is induced in the field about 1-1.5 week after rice transplanting. It forms a thick mat on water. Azolla can double its biomass in 3-5 days and assimilate 30-80 kg N/ha.

b) Phosphorus mobilizer biofertilizers

i. Phosphate solubilizers: Phosphorus solubilizing bacteria has ability to solubilize soil phosphate and increase P availability by secreting organic acids. These bacteria belongs to genera *Pseudomonas* and *Bacillus.* Some P solubilizing fungi also belongs to genera *Penicillium* and *Aspergillus.* Inoculation of seedlings or seeds with microphos biofertilizers can provide around 30 kg P_2O_5. These microorganisms secrete organic and inorganic acids such as malic acids, citric acid, formic acid, acetic acid etc. They reduced soil pH and caused dissolution of bound form of phosphorus. Bacillus grows on sulphur in soil and sulphuric acid is synthesized which dissolves phosphate from rock phosphate and make it available for plant use.

ii. Phosphate absorbers: Mycorrhizae are mutualistic symbiosis or association between roots and fungi present in soil. These are the member of kingdom Basidiomycetes, Zygomycetes and Ascomycetes. Vesicular-arbuscular mycorrhiza (VAM) increase the P nutrition along with its mobility. Through VAM plants are able to take P from soil zone not visited by root system. The VAM has also been reported to improve the uptake of zinc, copper and water. VAM are formed by association of phycomycete fungi and most of the agricultural crops. They store P as phospholipids. VAM inoculums can be prepared by mixing finely chopped roots of VAM infected host in sterile soil. Maize, sorghum and other grasses are suitable host for VAM inoculation. VAM culture can be used for all crops including grasses, legumes and cereals.

c) Organic matter decomposing bio-fertilizers

Insoluble contents of organic matter are cellulose and lignin and delay the composting process. Cellulose decomposing microorganisms are Chaetomium, Trichoderma, Aspergillus, Penicillum fungi and bacteria such as Cellulomonas, Clostridium, Cytophaga, Arthrobactor, and Actinomycetes, Nocardia and Streptomyces. Lignin decomposing fungi are cephalosporium, Humicola, etc. The decomposition of lignin is done by fungi.

Problems in Biofertilizers

1. Unawareness of biofertilizers
2. Unavailability of biofertilizers .
3. Poor quality biofertilizers or biofertilizers of expired date.
4. Transport and storage conditions that destroy the microbial

3- INORGANIC FERTILIZERS

Improved cultivars demand large quantities of nutrients due to their high yield potential. As such, low analysis organic manures and biofertilizers are not in a position to meet the nutrient needs of the crop. Until all the available resources of organic manure are fully tapped, there is need for supplementing at least part of plant nutrients, through inorganic fertilizers. It reported that inorganic fertilizers efficiency increased by its integration with organic manures and bio fertilizers. This will also reduce the environmental pollution.

4. SUSTAINABLE UTILIZATION OF WATER RESOURCES

A. Ground water use consistent with aquifer recharge

Ground water has a good source of irrigation water. However, much of the present practices of utilization are not sustainable because they largely depend upon luxurious use of water. The decline in ground water levels in certain areas has resulted in decrease in well yield, failure of wells/tube wells, increased pumping costs and higher consumption of energy and ingress (intrusion) of sea water in coastal areas. Thus, depletion of ground water needs to be arrested by:

i. Integrated approach for control of declining water table

1. Reduced ground water draft through

1. Enhancing surface water supply by developing new projects, inter zonal transfer of water, storage of surplus water, and renovation of water course,
2. Crop diversification,
3. Optimizing water use in rice fields,
4. Minimizing the gap between demand and supply,

5. On-farm water management,
6. Feasibility of exploiting deep aquifers.

2. Increased ground water potential by artificial ground water recharge through

1. Existing network of surface drainage system,
2. Percolation tanks, water harvesting structure and water shed management in upper catchments.
3. Diverting surplus water from rivers and streams to declining water table areas.

ii. Artificial ground water recharge

Ground water resources can be augmented through artificial recharge. The success of ground water recharge depends on water quality available, suitability of site and appropriate recharge technique. Water resources, which can be used for artificial ground water recharge, include.

1. Surplus monsoon runoff

2. Surplus Canal Water: During rainy days, water may not be required for irrigation but will have to be released for other requirements (hydropower). Canal water during this period, therefore, may be utilized for ground water recharge.

2. Sewage Water: In Pakistan, the sewage is collected in temporary pumping stations and pumped either on to land for irrigation or into drains or in some cases it is left to find its way into depressions where it stagnates.

B. Water Conservation

Water conservation in irrigated areas can be achieved by

i. Reducing conveyance losses

Conveyance losses account for 40 to 50 % of the water delivered into a canal and half of this value at farmer field's channels. In order to reduce these losses, lining of canal network should be done with due importance to economic considerations. However, water courses, which contributed very little to ground water, should be lined for efficient conveyance and distribution of water.

ii. Canal water management

The water allowance, the capacity factors and the irrigation intensities were designed keeping in view the availability of irrigation water and irrigation demands of the cropping systems prevalent at that time since a major change has occurred in cropping pattern, ground water development, cropping intensity, irrigation etc. This has resulted in a mismatch between demand and supply during the crop period. This gap can be minimized by revising the water allowance and the capacity factor, according to the irrigation requirements of existing crops, quality and availability of ground water.

iii. On-farm water management

Reducing application losses

Application efficiency of surface methods of irrigation is only 30-50% compared to that of attainable level (60 -80%) because these methods are not suitable to the soil type stream size, , and slope. In row crops like sugarcane, cotton, sunflower we can save 30-40% water by using ridge and furrow irrigation method as compared to flood irrigation. Similarly, about 30-40% water can be saved with sprinkler or drip irrigation in water scarcity areas, having condition conducive to their application.

Irrigation scheduling

Where irrigation water is abundant, irrigation should be reported before yield or quality reduction due to water stress that develops in the field. In case of rice, intermittent submergence, which includes rotations and occasional submergence can save irrigation water up to 50% depending on soil type.

The first step for irrigation scheduling with limited water is to assess the relative sensitivity of different growth periods to water stress. Irrigation with limited water should be so managed that the inevitable stress synchronizes with the least sensitive stages.

Precision land leveling

Precision land leveling/grading is essential for efficient utilization, uniform distribution of irrigation water, quick removal of excess rain water in humid and sub humid areas and conservation of rain water in arid and semiarid areas. In surface method of irrigation, land leveling is essential for high application efficiency.

C. Water Harvesting

i. In-situ rainwater harvesting

It can be achieved by increasing infiltration rate with deep ploughing and by keeping soil surface relatively rough. On lands having slopes up to 1 to 2%, water conservation could be by bunding, land leveling and contour cultivation. On lands having 2 to 6% slopes, graded contour bunds are ideal and on slopes it is from 6-33%.

ii. Ex-situ rainwater harvesting

Arid and semi-arid areas received low and erratic rainfall with high intensity of short duration results in high runoff with little moisture storage. Harvesting and storage of runoff provides lifesaving irrigation to the standing crops during dry spells and for a second crop during the winter season. Roof top collection, dug out ponds, storage tanks, gully control structures, small dams are the main ex-suit rainwater harvesting techniques. These technologies are highly location specific.

D. Safe Use of Saline Water

Management practices for optimum crop productivity with saline water must aim at preventing building up of salinity in the root zone.

i. Crop Management

1. Selection of crops

Tolerance to salinity or sodicity varied among the crops. Where there is not possibility of change the quality of water, selection of crop is main focus for successful crop production. . Oil seed crops requires small amount of water, can tolerate under salinity to a greater extent, whereas most pulse crops are very sensitive to salts. Crops like sugarcane and rice require more water should not irrigate with brackish water as these augment the salinity problems.

2. Growth stages

During initial stages, plant roots are limited to few cm, where salts are accumulated due to evaporation. Germination and initial stand establishment are the most critical stages, require strategies to reduce the salinity at root zone. Other critical stages are the change in phase like vegetative to reproductive and heading and flowering. Otherwise, tolerance to salinity increases with the age.

3. Crop varieties

Tolerance potential for salinity varies among the crops or crop varieties. A negative correlation has been reported between tolerance and crop yield potential. Varieties showing stable yield under saline conditions should be preferred.

ii. Irrigation management

1. Leaching requirement for salt balance

Areas where highly saline waters are used are usually mono cropped. Only salt tolerant crops are grown during winter. In such areas, rainfall received during monsoon is utilized for meeting the leaching requirements and thus maintaining the salt balance. A leaching strategy that can work well is to apply saline water for boosting the antecedent (prior, preceding) moisture contents and reducing salinity levels before the onset of monsoon. The refill of the surface soil with water just before the onset of monsoon will enhance salt leaching during 'kharif' rains. In addition to amount and frequency of rains, or water, salt leaching with rains/water depends on soil texture.

3. Pre-sowing irrigation

It is usually given to ease tillage, seed setting, seed bed conditions and provide water to the root zone for seed germination and seedling establishment. In saline soils, pre-sowing irrigation also leach the soluble salts below the seeding or root zone that minimize the effect of salt and help in seedling establishment.

4. Cyclic use of multi quality waters

The strategy is the judicial use of brackish water. It involves use of canal water at most sensitive growth stages, crops grown in sequence and use of saline water at other stages. In this way, we can minimize the harmful effects of salinity. Crops can be maintained very close to that with good quality water by skipping saline water at initial growth stage. Good and saline waters applied alternatively can also be followed if circumstances demand. Irrigation with saline water should not be done at most critical stages such as seedling phase. Cyclic use is better than mixing.

i. AMENDMENTS NEEDED

Chemicals amendments are extensively used in sodic soil the help to mitigate the adverse effects of Sodicity. Application of gypsum is required in such soils. In rain-fed areas, application of gypsum before onset of monsoon is better.

ii. PLANTING PROCEDURE

Under saline areas, low seed germination is a major constraint. . Pre-sowing or soaking irrigation is possible solutions to attain required germination percentage. This practice will leach the salt from seeding or root zone and provides good quality water to seeds that need for germination processes. Use of higher seed rate is another option that will provide higher plant population which compensate the unhealthy plant due to salinity.

5. AGRO-FORESTRY

Growing of both trees and crops or pastures either mixed in space or time is called as agroforestry. One of the major objectives of agroforestry in land use is to maintain the productive capacity of land on sustainable basis by maintaining soil fertility through erosion control and the addition of organic matter. In this system fertility loss from the crop components are balanced by gaining from trees. Trees play two main roles in erosion control, supplementary and direct. In the supplementary role, erosion is controlled generally by conventional means, such as earth bank and ditches, terraces or grass strips. The trees help in stabilizing these conservation structures and make productive use of land they occupy. In the direct role, the trees themselves play a significant role in erosion control.

6. INTEGRATED NUTRIENT MANAGEMENT:

Integrated plant nutrient system (IPNS) aims to develop a system to maintain soil fertility and supply of plant nutrient to an optimum level for sustaining the crop productivity. This also refers to the use of all possible sources of nutrients in an integrated manner.

Benefits:

1. Enhances the availability of both applied and native soil nutrients
2. Synchronizes the nutrient demand set by the
3. Maintain physical, chemical, and biological health of soil.
4. Reduce the soil applied fertilizers or nutrients leakage to water bodies or atmosphere.

Major components of INM, excluding inorganic fertilizers can be grouped into two broad groups: organic manures including farm organic wastes and bio-fertilizers.

1) Organic Manures:

Bulky organic manures have been the major traditional means, sustaining plant nutrients in the soil throughout history and these are equally as important today. It may be in-situ or ex-situ manuring.

a) In-situ Organic Manuring: This is the method of manuring at soil site there are two types of in-situ manuring: by animals at site and manuring with plants at site (green manuring).

- **In-situ manuring by animals:** This is the wide spread traditional practice in areas where cattle, buffalos, sheep's and goats are kept during night in the open lands and later ploughed the droppings directly into the soil.

- **In-situ manuring with plants (green manuring):** All leguminous crop producing around 15 t ha^{-1} of green matter will add about 50kg nitrogen per ha. The following are some examples of green manure crops:

Sesbania rostrata (rostrata)

Sesbania speciosa (sesbania)

Sesbania aculeata (dhaincha)

Crotalaria juncea (sunhemp)

Nitrogen content varies from 2-4% green manure crops based on dry weight basis.

Green leaf manure: Dried green leaf manure provides about 1.5-2.5% N

b) Ex-situ Organic Manuring:

Farm yard manure (FYM) used to be the major source of supplying nutrients to crops in traditional agriculture before the introduction of inorganic fertilizers. One ton of FYM supplies 112, 45, 2.5, 4.5 kg organic matter N, P, and K, respectively.

11.6 Benefits and Constraints of Sustainable Agriculture

11.6.1 Benefits/Advantages

1. Economic benefits

- Increase the efficiency and productivity of agricultural systems, thus contributing to improvement of farmers livelihoods.
- Optimize natural resource consumption e.g., water and energy, while maintaining or enhancing environmental services of water shed or landscape.

2. Environmental benefits

- Improve farmland productivity and thus generate opportunities to preserve wildlife habitats from further change to agriculture
- Increasingly embattled pest management and precision farming strategies
- keep and enhance ecosystem health particularly through biodiversity conservation, soil and water quality management.