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13. Soil Management Practices in Conservation Agriculture

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Abstract:

Conservation agriculture (CA) has emerged as a sustainable approach to address the challenges of modern agriculture, such as soil degradation, erosion, and declining soil fertility. This abstract explores various soil management practices within the framework of conservation agriculture. The primary focus is on techniques that promote the enhancement and preservation of soil health, while simultaneously improving agricultural productivity and minimizing environmental impacts. Key soil management practices discussed include minimum tillage, cover cropping, and crop rotation. These practices contribute to reduced soil disturbance, maintenance of organic matter content, and the prevention of soil erosion. The adoption of minimum soil disturbance practices, such as no-till or reduced tillage, is a cornerstone of conservation agriculture. These practices help preserve soil structure, minimize soil erosion, and maintain organic matter content. Cover cropping, another integral component of CA, involves planting cover crops between cash crop cycles to prevent soil erosion, enhance nutrient cycling, and suppress weeds. Cover crops contribute to increased soil organic matter, microbial diversity, and overall soil fertility.

13.1 Introduction:

Conservation agriculture is an innovative farming approach aimed at preventing the depletion of arable land and revitalizing degraded lands. It revolves around three key principles: the maintenance of a continuous soil cover, minimal disturbance of the soil, and the diversification of plant species. By adhering to these principles, conservation agriculture contributes to sustainable farming practices and the preservation of the environment.

Conservation agriculture principles are universally applicable to all agricultural landscapes and land uses, with locally adopted practices. The aim is to minimize or completely avoid mechanical soil disturbance and optimize the application of external inputs, including agrochemicals and plant nutrients of mineral or organic origin, so as not to disrupt biological processes. The soil is a vital repository of nutrients essential for plant growth, animal life, and millions of microorganisms. However, its life cycle is compromised if it becomes unhealthy due to various factors and techniques. Committed individuals dedicated to soil conservation play a crucial role in maintaining soil fertility and productivity while safeguarding it from erosion and degradation.

13.2 Soil Conservation (Management):

Soil conservation, also known as soil management, encompasses a range of strategies aimed at safeguarding soil from degradation. The fundamental principle of soil conservation lies in viewing soil as a thriving ecosystem, wherein various organisms play vital roles in maintaining a fertile and healthy environment. These organisms contribute to the decomposition of organic matter, nutrient release, and facilitation of air and water circulation. By adopting these practices, we ensure the sustainable preservation of soil health and productivity.

Figure 13.1: Soil Conservation (Management)

As a crucial aspect of soil conservation, the sustenance of various organisms within the soil heavily relies on the presence of deceased plant and animal materials, serving as their primary source of sustenance and energy. Therefore, to ensure effective soil conservation, it becomes imperative to consistently reintroduce organic matter back into the soil. This organic matter plays a vital role in establishing favorable soil structure and enhancing water retention capacity. Moreover, it facilitates efficient water infiltration while shielding the soil from erosion and compaction threats.

Besides safeguarding soil life and organic matter, soil conservation is guided by several other principles, which include:

- Ensure effective surface runoff management by implementing appropriate strategies to prevent erosion and sedimentation.
- Protect bare exposed soil areas, especially on steep slopes and highly vulnerable sites.
- Additionally, take measures to protect downstream watercourses from potential pollution and sedimentation issues.

Soil conservation is an ongoing and dynamic process that requires unwavering dedication from practitioners. The initial and essential step is acquiring a comprehensive understanding of the land resource. This entails identifying areas where the soil is highly permeable and at risk of groundwater contamination due to excessive pesticide use, as well as recognizing regions prone to water erosion due to a combination of slope and soil texture.

This crucial knowledge forms the foundation for devising an effective and tailored conservation strategy. Without such insight, developing an appropriate plan for soil conservation becomes unattainable.

The subsequent stages involve the identification or anticipation of problematic areas, selection, and application of soil conservation methods, along with the maintenance of control structures. The ultimate phase revolves around consistently monitoring the plan's efficacy and making appropriate adjustments when needed.

13.3 Good Reasons to Practice Soil Conservation:

- The primary objective is to maintain an optimal level of organic matter and biological activity within the soil. These fundamental components contribute significantly, accounting for 90 to 95 percent of the overall soil productivity.
- Another crucial goal is to secure a stable food supply at reasonable prices. Soil conservation has been scientifically proven to enhance both the quality and quantity of crop yields in the long run by preserving topsoil and sustaining the soil's productivity over time.
- Additionally, the aim is to produce enough food not only to meet our own needs but also to address food shortages in third-world countries.
- Lastly, promoting soil conservation serves to save farmers money. The detrimental effects of erosion currently lead to an annual loss of over $90 million in farmers' income due to decreased crop yields and nutrient depletion from the soil. By implementing soil conservation practices, farmers can mitigate these financial losses and ensure more sustainable agricultural practices.
- Soil conservation efforts aim to save citizens money by addressing the costly impact of soil erosion, which currently amounts to an additional $9.1 million annually. Recent research suggests that the actual cost might be even higher, making soil conservation all the more vital for financial savings.
- One of the critical goals is to enhance water quality. Clean water is essential for all forms of life to thrive. Soil erosion from agricultural and urban areas contributes

significantly to sedimentation and water contamination, making soil conservation crucial for safeguarding water supplies.

- Soil conservation practices play a crucial role in improving wildlife habitat. By implementing measures such as buffer strips, windbreaks, and restoring soil organic matter, the overall environment becomes more favorable for various wildlife species.
- Soil conservation efforts are also motivated by aesthetic reasons, as they contribute to the creation of more attractive and picturesque landscapes. Preserving and restoring healthy soils can enhance the visual appeal of the surroundings.
- An important objective is to establish an environment free of pollution, providing a safe and healthy place for human habitation. Soil conservation contributes to overall environmental protection, ensuring cleaner air, water, and surroundings.
- Protecting and conserving soil resources is essential for the future of our children. By maintaining healthy soil, we secure a foundation that can sustain life for generations to come. As the saying goes, the land is not solely inherited from our forefathers; instead, it is borrowed from our children, emphasizing the responsibility to preserve it for their benefit.

13.4 Soil Management Techniques:

Soil serves as the foundation for agriculture, making its proper management crucial for maintaining long-term agricultural productivity. Regrettably, soil erosion often goes unnoticed until it reaches severe levels, where deep channels impede cultivation practices.

However, the reality is that soil erosion starts to occur at unsustainable levels even when small rills become visible in the fields.

Identifying and addressing erosion at its early stages is essential to safeguard this valuable resource and ensure the sustainable growth of agriculture.

Indeed, soil stands as the fundamental resource upon which agriculture relies. To ensure sustainable long-term agricultural productivity, it is imperative to exercise proper management of this invaluable asset. Regrettably, soil erosion often comes to attention only when its impact becomes visibly drastic, such as channels cutting deeply through fields, impeding cultivation practices. However, it is crucial to recognize that soil erosion reaches unsustainable levels even when small rills become noticeable in the fields.

Thus, proactive measures and early identification are essential to effectively combat soil erosion and preserve the productivity of agricultural lands. By addressing erosion concerns at their early stages, we can safeguard the health and resilience of the soil, promoting a more sustainable and prosperous agricultural future.

There are two distinct approaches to soil conservation, namely mechanical measures and biological measures. Mechanical measures encompass the construction of enduring or semi-permanent structures, such as terracing, bunding, trenching, and check dams. On the other hand, biological measures consist of vegetative strategies, including forestry, agroforestry, horticulture, and agricultural or agronomic practices.

13.4.1 Biological Measures (Agronomic/Agricultural and Agroforestry):

Agronomic measures are applicable in the landscape of ≤2% slope. Agronomic measures reduce the impact of raindrops through the covering of soil surface and increasing infiltration rate and water absorption capacity of the soil which results in reduced runoff and soil loss through erosion. These measures are cheaper, sustainable, and may be more effective than structural measures. Important agronomic measures are described below.

A. Contour Farming:

Contour farming is a highly effective agronomic measure for soil and water conservation, particularly in hilly and sloping landscapes. It involves carrying out all agricultural operations, such as plowing, sowing, and inter-culturing, along the contour lines of the land. The formation of ridges and furrows across the slope creates a series of small barriers that slow down the flow of water, reducing the velocity of runoff and minimizing soil erosion and nutrient loss. The benefits of contour farming are significant and vary depending on the specific environmental conditions of a particular area:

- **Reduced soil erosion**: By slowing down runoff, contour farming prevents the rapid removal of soil particles, reducing erosion and conserving the fertile topsoil.
- **Enhanced infiltration**: The ridges and furrows improve water infiltration by increasing the time of concentration, allowing water to seep into the soil rather than running off the surface. This is particularly valuable in regions with low rainfall, as it helps conserve soil moisture and improves plant water availability.
- **Improved soil moisture retention**: In low rainfall areas, contour farming helps to trap and store rainwater, making it available for plant uptake over an extended period.
- **Minimized nutrient loss**: As the soil is better retained on the field, the loss of valuable nutrients, such as nitrogen and phosphorus, is reduced, benefiting crop productivity.
- **Increased crop productivity**: Conserving soil fertility, moisture, and nutrients ultimately improves overall crop productivity.

Contour farming is a valuable agronomic measure that offers numerous benefits for soil and water conservation in hilly agro-ecosystems and sloping lands. Proper implementation and adaptation to local conditions can greatly enhance its effectiveness and contribute to sustainable agriculture and improved crop productivity.

B. Choice of Crops:

Choosing the appropriate crop plays a vital role in soil conservation. Several factors should be taken into account, including the intensity and critical period of rainfall, market demand, climate, and the farmer's available resources. Opting for a crop with excellent biomass, ample canopy cover, and an extensive root system is crucial as it aids in safeguarding the soil against erosive rainfall impact and obstructing runoff, ultimately reducing soil and nutrient loss. Certain crops, like sorghum, maize, and pearl millet, which grow in rows or tall structures, may promote erosion by exposing the soil and facilitating the erosion process. On the other hand, crops that grow closely together, with a dense canopy cover and vigorous root system, such as cowpea, green gram, black gram, and groundnut, are better suited for mitigating soil erosion. To maximize canopy density, it is advisable to use a higher seed rate while planting the chosen crop. This practice encourages a more comprehensive coverage, further enhancing soil protection and erosion reduction.

Figure 13.2: Choice of Crops

F. Crop Rotation:

Figure 13.3: Crop Rotation

Crop rotation is a beneficial agricultural practice that involves cultivating different types of crops successively on the same field. The primary aim is to maximize profits with minimal investment while preserving soil fertility. In contrast, monocropping, which involves planting the same crop repeatedly, can lead to soil nutrient depletion and reduced fertility over time. Incorporating legume crops into the crop rotation brings several advantages, such as reducing soil erosion, restoring soil fertility, and conserving soil and water resources. Additionally, when crop residues are integrated into the soil after harvest, it enhances the organic matter content, overall soil health, and helps in reducing water pollution.

An appropriately planned crop rotation that includes high canopy cover crops can significantly contribute to sustaining soil fertility. These rotations effectively suppress weed growth, decrease pests and disease infestation, improve the efficiency of resource utilization, and enhance overall system productivity while simultaneously reducing soil erosion. By adopting crop rotation practices, farmers can achieve sustainable and profitable agricultural production while safeguarding the long-term health and productivity of their soil.

D. Cover Crops:

Figure 13.4: Cover Crops

Cover crops, also known as close-growing crops with high canopy density, play a crucial role in protecting the soil from erosion. Among cover crops, legume crops are particularly effective in safeguarding soil health due to their good biomass and dense canopy. The success of cover crops in erosion control depends on their crop geometry and the development of a robust canopy, which helps intercept raindrops and minimize soil surface exposure to erosion.

Studies have indicated that legume cover crops outperform other options like cultivated fallow and sorghum in providing better cover and protection against runoff and soil loss.

Among the legume cover crops, cowpea, green gram, black gram, and groundnut have been found to be particularly effective in reducing erosion and preserving soil integrity. By strategically incorporating these cover crops into crop rotations or leaving them on the field during periods of fallow, farmers can greatly enhance soil conservation efforts, reduce erosion-related issues, and promote sustainable agricultural practices.

Advantages:

Cover crops offer a range of valuable benefits that contribute to soil conservation and agricultural productivity

- Protection from Erosion: Cover crops shield the soil surface from the erosive impact of raindrops and the forces of wind, reducing soil erosion.
- Obstacle to Water Flow: They act as barriers in water flow, slowing down its velocity, which helps in decreasing runoff and soil loss during heavy rainfall events.
- Increased Organic Matter: Cover crops contribute to soil organic matter content through the incorporation of their residues into the soil. This enhances soil fertility and overall soil health.
- Biological Nitrogen Fixation: Legume cover crops have the unique ability to fix atmospheric nitrogen through symbiotic relationships with nitrogen-fixing bacteria in their root nodules. This process enriches the soil with available nitrogen, benefiting not only the cover crop but also subsequent crops in the rotation.
- Improved Water Holding Capacity: The presence of cover crops helps improve the soil's ability to retain moisture, reducing water loss through evaporation and ensuring better water availability for the crops.
- Enhanced Soil Properties: Cover crops can positively influence soil structure, aeration, and nutrient availability, leading to improved overall soil properties.
- Weed Suppression: A well-established cover crop can effectively suppress weed growth, reducing competition for resources and promoting the growth of desired crops.
- Increased Crop Productivity: By providing a favorable environment for the main crop and subsequent crops, cover crops can lead to increased agricultural productivity.
- Overall, incorporating cover crops into agricultural practices can bring multiple advantages, making them a valuable tool for sustainable soil conservation and farming. Protection of soil from the erosive impact of raindrops, runoff, and wind.
- Act as an obstacle in water flow, reduce flow velocity, and thereby reduce runoff and soil loss.
- Increase soil organic matter by residue incorporation and deep root system.
- Improve nutrients availability to the component crop and succeeding crops through biological nitrogen fixation.
- Improve water holding capacity of the soil.
- Improve soil properties, suppress weed growth, and increase crop productivity.

E. Intercropping:

Figure 13.5: Intercropping

Intercropping refers to the practice of cultivating two or more crops simultaneously in the same field, often arranged in definite or alternate row patterns. The classification of intercropping can be based on the types of crops used, soil type, topography, and prevailing climatic conditions. Common types of intercropping include row intercropping, strip intercropping, and relay intercropping, each offering specific benefits based on its configuration.

The primary goal of intercropping is to make efficient use of resources, space, and time dimensions. By combining erosion-permitting and erosion-resisting crops, farmers can optimize soil conservation efforts. Selecting crops with different rooting patterns is essential to ensure effective soil coverage, which reduces the direct impact of raindrops and minimizes soil erosion.

Overall, intercropping provides significant advantages in terms of better soil coverage, reduced soil erosion from the direct impact of raindrops, and improved soil protection. By strategically planning and implementing intercropping practices, farmers can enhance soil health, maximize productivity, and promote sustainable agricultural practices.

F. Strip Cropping:

Figure 13.6:

Strip cropping is a farming practice that involves growing alternating strips of erosion-permitting and erosion-resistant crops in the same field. This technique is employed to reduce soil erosion, control runoff, and maintain soil fertility. The erosion-resistant crops, which typically have deep root systems and high canopy density, act as natural barriers, protecting the soil from the impact of raindrops and slowing down the velocity of runoff. By implementing strip cropping, the runoff velocity is reduced, which allows more time for water to infiltrate into the soil, resulting in increased soil moisture. This additional soil moisture can enhance crop production, as it provides a more favorable environment for plant growth. In addition to mitigating soil erosion and nutrient loss, strip cropping can also be beneficial in preserving soil structure, preventing sedimentation in water bodies, and supporting biodiversity in the agricultural landscape. Overall, it is a sustainable practice that contributes to the long-term health and productivity of the soil.

Types of Strip Cropping:

Contour strip cropping: Contour strip cropping is indeed a farming practice where alternating strips of erosion-permitting and erosion-resistant crops are grown along the contour lines of the sloping land.

The main objectives of contour strip cropping include:

A. **Reducing the direct impact of raindrops on the soil surface**: By growing erosion-resistant crops in alternate strips, the force of raindrops hitting the soil is reduced, minimizing soil detachment and erosion.
B. **Reducing the length of the slope**: The contour strips act as barriers to slow down the flow of water down the slope, effectively dividing the long slope into shorter segments. This reduces the potential for concentrated flow, which can lead to soil erosion.
C. **Slowing down runoff flow**: Contour strip cropping helps to control and disperse runoff water, preventing it from gaining high velocity and causing erosion.
D. **Enhancing rainwater absorption into the soil profile**: By slowing down the flow of water and reducing surface runoff, more water can infiltrate into the soil, increasing soil moisture and promoting better plant growth.

Overall, contour strip cropping is an effective soil conservation practice, especially on sloping terrains, as it helps to minimize soil erosion, retain soil fertility, and improve water availability for crops. It is a sustainable agricultural approach that contributes to the long-term health and productivity of the land.

Figure 13.7: Strip Cropping

- **Field strip cropping -** The specialized strip cropping you described, where crops are planted in parallel bands across a slope but do not follow contour lines, with alternating bands of grass or other close-growing species and cultivated crops, is known as "alley cropping" or "agroforestry strip cropping.".

Figure 13.8: Field Strip Cropping

- **Wind strip cropping:** Wind strip cropping is a conservation technique used to control soil erosion caused by wind., it involves planting tall-growing row crops (like maize, pearl millet, and sorghum) along with close or short growing crops in alternating strips across the direction of the prevailing wind, without regard to the contour of the land.

Figure 13.9: Wind Strip Cropping

- **Permanent or temporary buffer strip cropping:** It is the growing of permanent strips of grasses or legume or a mixture of grass and legume in highly eroded areas or in areas that do not fit into regular rotation, i.e. steep or highly eroded, slopes in fields under contour strip cropping. These strips are not practiced in normal strip cropping and generally planted permanent or temporary basis.

Figure 13.10: Permanent or Temporary Buffer Strip Cropping

Purposes:

- Reduce soil erosion from water and wind.
- Strip Cropping reduces the rate of soil erosion and the runoff velocity.
- Increasing the infiltration rate of the soil under cover condition.
- Reduce the transport of sediment and other waterborne contaminants.
- Protect growing crops from damage by windborne soil particles.
- Improve water quality.

G. Mulching:

Figure 13.11: Mulching

Mulch is any organic or non-organic material that is used to cover the soil surface to protect the soil from being eroded away, reduce evaporation, increase infiltration, regulate soil temperature, improve soil structure, and thereby conserve soil moisture.

Mulching prevents the formation of hard crust after each rain. The use of blade harrows between rows or inter-culture operations creates "dust mulch" on the soil surface by breaking the continuity of capillary tubes of soil moisture and reduces evaporation losses. Mulching also reduces the weed infestation along with the benefits of moisture conservation and soil fertility improvement.

Hence, it can be used in high rainfall regions for decreasing soil and water loss, and in low rainfall regions for soil moisture conservation. Organic mulches improve organic matter and consecutively improving the water holding capacity, macro and micro fauna biodiversity, their activity, and fertility of the soil .Inorganic mulches have a longer life span than organic mulches and can reduce soil erosion, water evaporation losses, suppress weeds but cannot improve soil health.

This practice is costly and labor intensive therefore, suitable for cash crops such as fruits and vegetables. Polyethylene mulch is commonly used for the conservation of soil and water resources to increase crop productivity.

H. Conservation tillage:

Conservation tillage is an important agricultural practice that involves leaving a significant amount of crop residue on the soil surface before and after planting the next crop. The main goal is to reduce soil erosion and promote other beneficial effects, such as carbon sequestration and improved soil health.

Benefits of Conservation Tillage:

- **Reduced soil erosion**: Crop residue cover protects the soil from water and wind erosion.
- **Carbon sequestration**: The presence of crop residues contributes to increased soil organic carbon content**.**
- **Improved infiltration**: Conservation tillage improves water infiltration into the soil, reducing runoff.
- **Soil moisture conservation**: Crop residue cover reduces evaporation losses and helps retain soil moisture.
- Enhanced soil health: Conservation tillage improves soil structure, organic matter content, and nutrient cycling.
- **Increased productivity**: Better soil health and fertility lead to improved crop yields.
- **Soil compaction reduction**: Reduced soil disturbance can alleviate compaction issues.

Figure 13.12: Soil Compaction Reduction

I. Organic Farming:

Organic farming in relation to soil erosion and overall environmental friendliness. Organic farming practices focus on enhancing soil health and fertility through the use of natural, organic sources for plant nutrient supply, such as farmyard manure (FYM), compost, vermicompost, green manure, and residue mulching. These practices lead to several positive effects on soil erosion:

- **Continuous soil surface cover**: Organic farmers often use cover crops, green manure, and residue mulch, which help maintain a protective cover on the soil surface. This cover acts as a barrier against raindrop impact and water runoff, reducing the erosive forces that lead to soil erosion.

- **High organic matter content:** Organic farming relies on the addition of organic materials, which increase the organic matter content in the soil. Higher organic matter content improves soil structure and stability, reducing the disintegration of soil particles and making the soil less susceptible to erosion.
- **Improved water infiltration**: Organic matter-rich soils have better water retention capacity and improved water infiltration. This helps prevent surface runoff and allows rainwater to penetrate the soil, reducing the potential for erosion.
- **Enhanced soil aggregation**: The presence of organic matter fosters the development of soil binding agents, such as polysaccharides. These agents help stabilize and strengthen soil aggregates, which further contributes to erosion reduction.
- **Reduced soil erodibility**: By improving soil structure, organic farming reduces soil erodibility, which refers to the soil's susceptibility to erosion under specific conditions.
- organic farming practices can significantly reduce soil erosion rates compared to conventional farming methods. The use of synthetic fertilizers and pesticides in conventional agriculture can lead to adverse environmental impacts, including soil degradation and erosion. On the other hand, organic farming focuses on sustainable and eco-friendly practices, which prioritize soil health and long-term crop productivity while minimizing negative environmental consequences.

J. Land Configuration Techniques:

Adoption of appropriate land configuration and planting techniques according to crops, cropping systems, soil type, topography, rainfall, etc. help in better crop establishment, intercultural operations, reduce runofff, soil and nutrient loss, conserve water, efficient utilization of resources and result in higher productivity and profitability. Ridge and furrow, raised bed and furrow, broad bed and furrow, and ridging the land between the rows are important land configuration techniques.

- **Ridge and furrow system:** Raising rainy season crops on ridges and *rabi* season crops in furrows reduces the soil crusting and ensures good crop stand over sowing on flat beds. Moreover, inter-row rainwater can be drain out properly during the monsoon period and collected in farm ponds, for life-saving irrigations and profile recharging for the establishment of *rabi* crops. It leads to the increased moisture content in soil profile which reduces moisture stress on plants during the drought period. This method is most suitable for wide-spaced crops viz. cotton, maize, vegetables, etc.

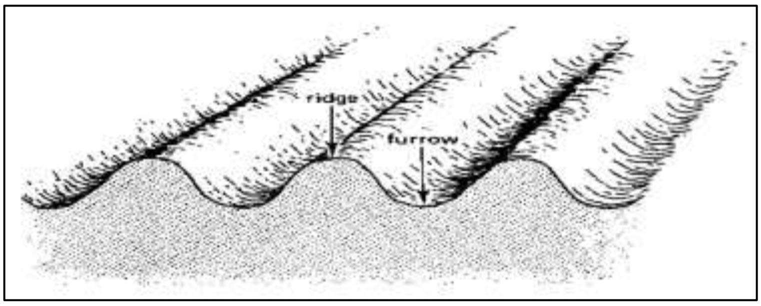

Figure 13.13: Ridge and Furrow System

- **Broad bed and furrow system:** This system has been developed by the ICRISAT in India. It is primarily advocated for high rainfall areas (>750 mm) having black cotton soils (Vertisols). Beds of 90–120 cm width are formed, separated by sunken furrows of about 50–60 cm wide and 15 cm depth. The preferred slope along the furrow is between 0.4 and 0.8% on Vertisols. Two to four rows of the crop can be grown on the bed, and the width and crop geometry can be adjusted to suit the cultivation and planting equipment.

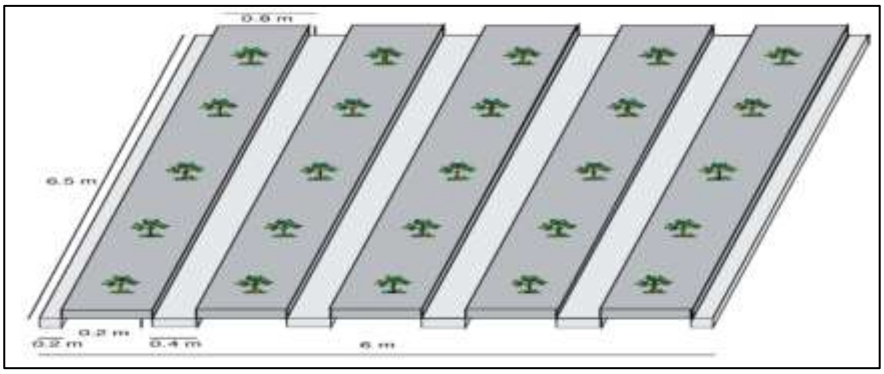

Figure 13.14: Broad Bed and Furrow System

Advantages:

- Increase *in-situ* soil moisture conservation
- Safely dispose of excess runoff without causing erosion
- Improved soil aeration for plant growth and development
- Easier for weeding and mechanical harvesting
- It can accommodate a wide range of crop geometry.

13.5 Agroforestry Measures:

Figure 13.15: Agroforestry Measures

Agroforestry is indeed a sustainable land management system that integrates the cultivation of trees or shrubs with agricultural crops and livestock on the same piece of land. This practice has gained attention for its numerous benefits, including effective soil conservation and sustainable agricultural production.

A. **Soil conservation**: Agroforestry systems help control soil erosion by providing a protective layer through the addition of leaf litter and organic matter from tree and shrub canopy. The leaf litter acts as a mulch, reducing the impact of raindrops on the soil surface and minimizing surface runoff, thus protecting against erosion.
B. **Soil health and moisture retention**: The incorporation of trees and shrubs in agroforestry systems improves soil health by enhancing organic matter content and microbial activity. This, in turn, enhances the soil's moisture retention capacity, reducing the risk of drought stress on crops.
C. **Crop productivity**: Agroforestry practices can positively impact crop productivity due to improved soil health, reduced erosion, and better water availability. The interaction between trees and crops can also create beneficial microclimates for certain crops, providing shade or wind protection.
D. **Environmental benefits**: Agroforestry helps mitigate environmental pollution by reducing the need for synthetic fertilizers and pesticides, thereby promoting a more sustainable and eco-friendly agricultural system.
E. **Economic benefits**: Apart from its environmental advantages, agroforestry also offers economic benefits to farmers. Trees in agroforestry systems can produce marketable products like fruits, nuts, timber, medicinal plants, and other non-timber forest products, contributing to farm income diversification.
F. **Soil erosion reduction:** Studies have shown that various agroforestry practices can reduce soil erosion rates by up to 10% compared to conventional agriculture. This is an essential contribution to land conservation and protection of natural resources. agroforestry is a multifaceted approach that offers a range of benefits, including soil conservation, improved soil health, increased crop productivity, and economic diversification through the production of marketable tree-based products. Its potential to reduce soil erosion and its positive impact on the environment and farm economy make it an attractive and sustainable land management system.

Types of Agroforestry Systems:

A. **Agri- Silviculture:** It is the growing of agricultural crops as a primary component with the secondary component of multipurpose trees (MPTs) on the same managed land unit. The tree species bind soil particles in the root zone and increase water infiltration, and reduce runoff.
B. **Agri-Horticulture:** Growing of agricultural crops and fruit trees on the same managed land unit is known as agri-horticulture. Fruit tree species like lemon (*Citrus limon*), mango (*Mangifera indica*), ber (*Ziziphus mauritiana*), and aonla (*Phyllanthus emblica*) can be successfully planted in agricultural fields and on degraded and low fertile lands with some restoration measures.
C. **Alley Cropping:** Growing of agricultural crops in the alley formed between the hedge rows of leguminous nitrogen-fixing tree species. This system is one of the effective measures for soil and water conservation in hilly areas.

D. **Silvi -Pasture System:** Raising grasses or livestock with MPTs on the same managed land unit is known as silvi-pasture system. This system has the potential to reclaim eroded and degraded lands. Mechanical measures combined with grass species cultivation are more effective for controlling soil erosion processes. The grass species such as, *Dichanthium annulatum (marvelgrass), Panicumantidotale (bluepanicgrass), Panicummaximum (Guineagrass), Brachiariamutica (para grass)* and *Pennisetum purpureum* (elephant grass) are important in ravine restoration.

13.6 Mechanical Measures:

Mechanical measures or engineering structures are designed to modify the land slope, to convey runoff water safely to the waterways, to reduce sedimentation and runoff velocity, and to improve water quality. These measures are either used alone or integrated with biological measures to improve the performance and sustainability of the control measures. In highly eroded and sloppy landscape biological measures should be supplemented by mechanical structures. A number of permanent and temporary mechanical measures are available such as terraces, contour bunding, check dams. The mechanical measures are preferred based on the severity of erosion, soil type, topography, and climate.

A. Bunding:

- **Contour bunding:** Contour bunding is used to conserve soil moisture and reduce erosion in the areas having 2–6% slope and mean annual precipitation of <600 mm with permeable soils. The vertical interval between two bunds is known as the spacing of bunds. The spacing of bund is dependent on the erosive velocity of runoff, length of the slope, slope steepness, rainfall intensity, type of crops, and conservation practices.

Figure 13.16: Contour Bunding

- **Graded bunding:** Graded bunds are made to draining out of excess runoff water safely in areas having 6–10% land slope and receiving rainfall of >750 mm with the soils having infiltration rate < 8 mm/h.

- **Peripheral bunds:** Peripheral bunds are constructed around the gully head to check the entry of runoff into the gully. It protects the gully head from being eroded away through erosion processes. It creates a favorable condition for the execution of vegetative measures on gully heads, slopes, and beds.

B. Contour trenching:

Trenches are constructed at the contour line to reduce the runoff velocity for soil moisture conservation in the areas having <30% slope. Bunds are formed on the downstream side of trenches for the conservation of rainwater. Trenches are of two types:

Figure 13.17: Contour Trenching

- **Continuous contour trenches:** Continuous contour trenches are constructed based on the size of the field in the low rainfall areas with the 10–20 cm trench length and 20–25 cm equalizer width without any discontinuity in trench length (10–20 m).
- **Staggered contour trenches (STCs)** Generally, these trenches are constructed in alternate rows directly beneath one another in a staggered manner in the high rainfall areas, where the risk of overflow is prominent. SCTs are 2–3 m long with 3–5 m spacing between the rows. Planting of tree species is done based on the land slope. It is highly effective in forestalling extension of gully head, soil loss, and arrest the overflow.

C. Terracing:

Figure 13.18: Terracing

Terraces are earthen embankments built across the dominant slope partitioning the field in uniform and parallel segments. Generally, these structures are combined with channels to convey runoff into the main outlet at reduced velocities. It reduces the degree and length of slope and thus reduced runoff velocity, soil erosion and improves water infiltration. It is recommended for the lands having a slope of up to 33%, but can be adopted for lands having up to 50–60% slope, based on socio-economic conditions of a particular region. Where plenty of good-quality stones are available, stone bench terracing is recommended. Sometimes, semi-circular type terraces are built at the downstream side of the plants, known as half-moon terraces. Based on the slope of benches, the bench terraces are classified into the following categories:

- **Bench terraces sloping outward:** These types of terraces are used in low rainfall areas having permeable soils. A shoulder bund is provided for stability of the edge of the terrace and thus has more time for rainwater soaking into the soil.
- **Bench terraces sloping inward (hill-type terraces):** These types of bench terraces are suitable for heavy rainfall areas where a higher portion of rainfall is to be drained as runoff. For this, a suitable drain should be provided at the inward end of each terrace to drain the runoff. These are also known as hill-type terraces.
- **Bench terraces with level top:** These types of terraces are suitable for uniformly distributed medium rainfall areas having deep and highly permeable soils. These are also known as irrigated bench terraces because of their use in irrigated areas.

D. Conservation Bench Terrace:

In the conservation bench terrace system, the land is divided into 2:1 ratio along the slope in which the upper 2/3 area (Donor area) contributes runoff to the lower 1/3 runoff collecting area (recipient area). The donor area is left in its natural slope condition. It is also known as the zing terrace and developed by Zing and Hauser in 1959. The runoff contributing area is used for cultivation of *kharif* while the lower 1/3 area with conserved soil moisture is used to cultivate rabi zcrops. This mechanical measure can be successfully applied in a semi-arid climate on mild sloppy lands (2–5%) for erosion control, water conservation, and improvement of crop productivity. This system can be used in silty loam to silty clay loam soils. CBT system resulted in the reduction of runoff from 36.3 to 7.4% and soil loss from 10.1 to 1.19 Mg ha^{-1} as compared to the conventional system of sloping border. An average reduction of 78.9 and 88.0% in runoff and soil loss, respectively reported in the CBT system over the conventional system.

13.7 Conclusion:

The land is finite and diminishing gradually due to the increasing rate of varied kinds of degradation and thus there is no alternative to expend cultivable land area. The only way is either increasing agricultural productivity per unit resource available or restoring the degraded lands. Healthy soil and availability of water are vital for productivity in all kinds of terrestrial ecosystems because plants require fertile soil with improved Biological-Physical-Chemical properties and good quality of water for their growth and development. Use of soil and water conservation measures including biological (agroforestry and agricultural) and mechanical measures (terracing, bunding, trenching, check dams, etc.) is imperative to reduce runoff, soil erosion and to improve soil quality, water quality, moisture conservation, and overall crop productivity in a sustainable way. Biological measures are economically feasible and environmental friendly; also improve soil properties along with the conservation of soil and water resources. Further, the combined use of biological and mechanical measures will help in improving and sustaining agricultural productivity.

Future Perspectives for Soil Conservation:

The burgeoning world population, food insecurity and natural resource degradation are the major issues in the present era of climate change. It has been projected that the world population will be ~10 billion in 2050. Further, the rapid industrial growth and intensive farming practices are expected to increase the pressure on land and water resources in near future. Therefore, a paradigm shift in soil and water conservation, and its management is needed for agricultural sustainability. The some of the future concern for soil and water conservation and sustainable agriculture are the following:

- Formulation of new policies and development of new technologies based on social, economic and cultural aspect of a particular regional.
- Implementation and adoption of effective conservation measures for sustaining agricultural productivity.
- Existing soil and water conservation practices should be improved and developed based on the level of natural resources degradation.
- Greater emphasis should be given on participatory approach for effective soil and water conservation.
- Post impact assessment and monitoring of soil and water conservation measures should be done to evaluate their efficacy in increasing productivity, monetary returns, and livelihood of the stakeholders.
- Development of cost effective conservation practices to restore the degraded lands and to sustain agricultural productivity.
- The efficient technologies for soil and water conservation should be demonstrated on farmers' fields with their active participation.
- Emphasis on research, education and extension of soil and water conservation effective technologies to the stakeholders.
- Adoption of efficient management practices and judicious use of soil and water resources.

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