KINGDOM OF ESWATINI

MINISTRY OF AGRICULTURE

SOIL HEALTH MANAGEMENT

Prepared:

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SOIL HEALTH MANAGEMENT

Soil health management refers to practices that aim to improve the biological, chemical and physical overall health and function of soil. Healthy soil supports thriving plant growth, enhances water retention, increases nutrient availability, and fosters a diverse community of soil organisms. It ensures that the soil remains productive, resilient and sustainable for agricultural use.

Why is it important

- ✓ Supports plant growth
- ✓ Improve water infiltration
- ✓ Reduce erosion and nutrient loss
- ✓ Supports biodiversity
- ✓ Builds resilience to climate change

Key Soil Health Management Principles

1. Minimal Soil Disturbance

    Use minimum tillage methods

2. Soil Cover

    Apply mulch, Leave crop residue, Cover crops (legumes, grasses)

3. Enhance biodiversity

    Crop rotation, Livestock integration, Diverse cover crop species

4. Maintain living roots

    Grow perennial crops, Extend growing season (cover cropping)

5. Nutrient management

    Apply compost/manure, Use organic and inorganic fertilisers, Soil testing

6. Manage water efficiency

    Rainwater harvesting, Efficient irrigation (drip, micro jets)

Soil Health Practices

Practice	Benefit
Composting	Adds organic matter and nutrients
Crop rotation	Breaks pests, diseases cycles, crop biodiversity
Mulching	Conserve moisture and suppresses weeds
Green manuring	Improves soil fertility and soil structure
Agroforestry	Prevents erosion, enriches soil and biodiversity
Soil testing	Determine amount and type of fertiliser to be used, O. M. ,pH
Fertiliser application	Adds nutrients
Lime application	Corrects acidic soils
Conservation agriculture	Minimum soil disturbance, add organic matter, suppress weeds, water infiltration

1. Composting

This is a natural process of recycling organic materials into a valuable soil amendment called compost. It is a natural way of breaking down organic waste, mimicking the decomposition that occurs on forest floors. This process is driven by microorganisms (like bacteria and fungi), insects, and worms, which feed on organic matter in the presence of oxygen and moisture.

How Composting Works

The core of composting involves combining nitrogen-rich materials (greens) and carbon-rich materials (browns) with water and air.

- **Greens-**These are typically fresh, moist materials like food scraps (fruits and vegetables peelings, coffee grounds, and tea bags), grass cuttings, and fresh plant cuttings. They provide nitrogen, which is essential for microbial growth.
- **Browns-**These are dry, woody, or fibrous materials such as dried leaves, shredded paper and cardboard, straw, wood chips, and small twigs. They provide carbon, which is the primary energy source for the microorganisms.
- **Water (Moisture)-**Just like any living organisms, the microorganisms need water to digest materials and thrive. The compost pile should be consistently moist, like a wrung-out sponge, but not waterlogged.
- **Air (Oxygen)-**Composting is an aerobic process, meaning it requires oxygen. Without enough oxygen, the pile can become anaerobic, leading to foul odors and slower decomposition. Turning the pile periodically helps introduce air.

As these components are mixed, microorganisms break them down, generating heat in the process. Over time, the materials transform into a dark, crumbly, earthy-smelling substance: compost.

Benefits of Composting

Composting offers numerous environmental, economic, and practical benefits:

- **Enriches Soil-**Compost is a fantastic soil conditioner. It improves soil structure, aeration, and drainage, while also enhancing its ability to retain water and nutrients.
- **Reduces Need for Chemical Fertilisers and Pesticides-**Compost provides a slow-release source of a wide range of nutrients, reducing or eliminating the need for synthetic fertilizers. Healthy soil and plants, bolstered by compost, are also more resistant to pests and diseases, minimizing the need for chemical pesticides.
- **Conserves Water-**By improving soil's water-holding capacity, compost helps retain moisture, leading to less frequent watering of plants and gardens.
- **Prevents Soil Erosion-**Compost helps bind soil particles together, reducing erosion by wind and water.
- **Supports Healthy Plant Growth-**The nutrients and beneficial microbes in compost promote stronger, healthier plant growth and higher crop yields.
- **Reduces Waste-**It diverts organic waste from landfills, which significantly reduces the amount of trash sent for disposal.
- **Reduces Greenhouse Gas Emissions-**When organic matter breaks down in landfills without oxygen (anaerobically), it produces methane, a potent greenhouse gas. Composting, being an aerobic process, prevents this methane production.
- **Creates Local Resource-**Composting keeps organic materials and their valuable nutrients within local communities, promoting a more circular economy.
- **Reduces Waste:** It diverts organic waste from landfills, which significantly reduces the amount of trash sent for disposal.
- **Reduces Greenhouse Gas Emissions:** When organic matter breaks down in landfills without oxygen (anaerobically), it produces methane, a potent greenhouse gas. Composting, being an aerobic process, prevents this methane production.

Types of Composting Methods

There are various composting methods, ranging from simple home setups to large-scale industrial operations:

Home Composting

1. Backyard Composting-This is the most common method for home gardeners. Organic materials are piled in a heap or contained in a bin. Regular turning helps aerate the pile and speed up decomposition.

2. Vermicomposting (Worm Composting)-This method uses ***specific types of worms*** (Indian Blue Worms, African Nightcrawlers) to break down food scraps and other organic matter. It is good for smaller spaces and produces nutrient-rich worm castings (worm manure) and "worm tea" (liquid fertilizer).

3. Bokashi Composting-This is an anaerobic fermentation process using an airtight container and a special ***bokashi bran*** inoculated with beneficial microorganisms. It breaks down all types of food waste, including meat and dairy, into a pre-compost material that then needs to be buried or added to a traditional compost pile to fully break down.

4. In-ground/Trench Composting-Involves burying food scraps directly into the garden soil, where they decompose naturally.

How to Start Composting at Home

A. Choose a Method and Location

Backyard Bin/Pile-Select a spot that is easily accessible, has good drainage, and is ideally on bare soil to allow microorganisms and worms to enter. Both sun and shade work.

Worm Bin-Can be kept indoors or outdoors in a sheltered area.

Bokashi Bin-Designed for indoor use.

B. Gather Materials

Greens-Fruit and vegetable scraps, coffee grounds, tea bags, grass cuttings, fresh plant trimmings, eggshells.

Browns-Dried leaves, shredded paper/cardboard (non-glossy, no plastic tape), straw, small twigs, sawdust (from untreated wood).

Avoid-Meat, dairy, oily foods, pet waste (from carnivorous animals), diseased plants, invasive weeds, treated wood.

C. Start Your Compost Pile/Bin

Layering (for bins/piles)-A common recommendation is to alternate layers of browns and greens, aiming for a higher ratio of browns (e.g., 2 parts brown to 1 part green).

Start with a base layer of coarse browns-(twigs, wood chips) for aeration and drainage.

Cut materials into smaller pieces-to speed up decomposition.

D. Maintain Your Compost

Moisture-Keep the pile moist, like a damp sponge. Water if it feels too dry. Cover to prevent it from getting too wet from rain.

Aeration (Turning)-Regularly turn the pile with garden fork to mix materials and introduce oxygen. This prevents anaerobic conditions and speeds up decomposition. For stationary bins, simply poking holes can help.

Balance-If the pile smells bad like rotten eggs, it might be too wet or have too many greens. Add more browns and turn it. If it is not breaking down, it might be too dry or lack nitrogen; add more greens and water.

E. Harvest Compost

Compost is ready for use anywhere from a few weeks to several months, depending on the method, materials, and management.

When it is dark brown, crumbly, and has an earthy smell. You should no longer be able to identify the original materials.

Harvest from the bottom of the pile, allowing the top layers to continue decomposing.

2. Crop Rotation

Crop rotation is an agricultural practice that involves planting different types of crops sequentially on the same plot of land over several growing seasons or years. Instead of growing the same crop repeatedly in the same spot, farmers strategically switch out the crops to achieve various benefits for soil health, pest and disease management, and overall farm productivity.

How Does Crop Rotation Work

The core principle behind crop rotation is diversity, different plants have different characteristics:

- **Nutrient Needs-**Some crops are ***heavy feeders*** that draw a lot of specific nutrients from the soil (e.g., cabbage), others, like legumes (beans, peas), are ***nitrogen-fixers*** that actually add nitrogen to the soil through a symbiotic relationship with bacteria.
- **Root Systems-**Crops have varying root depths. Deep-rooted plants (e.g., alfalfa, some grains) can break up compacted soil and bring up nutrients from deeper layers, while shallow-rooted plants help with surface soil structure.
- **Pest and Disease Susceptibility-**Pests and diseases often attack a particular crop or plant family. By rotating crops, you disrupt their life cycles, making it harder for them to establish and multiply.
- **Weed Suppression:** Different crops compete with different types of weeds. Rotating crops can help prevent the dominance of any single weed species that has adapted to a particular crop.

A typical crop rotation plan involves dividing a growing area into sections and cycling different crop families through those sections over a period of 2 to 5 years (or even longer in some traditional systems).

Key Benefits of Crop Rotation

1. **Improves Soil Health and Fertility**
    - **Nutrient Cycling-**Prevents the depletion of specific nutrients. Legumes add nitrogen, reducing the need for synthetic nitrogen fertilizers.
    - **Increased Organic Matter-**Incorporating cover crops or leaving crop residues from different plants adds diverse organic matter to the soil, improving its structure, water retention capacity, and microbial activity.
    - **Enhanced Soil Structure-**Different root systems help break up compaction, improve aeration, and promote healthy soil aggregates, leading to better water infiltration and reduced erosion.
2. **Manages Pests and Diseases**
    - **Disrupts Life Cycles-**Many pests and pathogens are host-specific. By rotating crops, you remove their food source or living environment, breaking their reproductive cycles and reducing their populations.

    - **Reduces Chemical Reliance-**Lower pest and disease pressure means less need for chemical pesticides, benefiting both the environment and human health.
3. **Controls Weeds**
    - **Diversifies Weed Pressure-**Different crops and their associated cultivation practices (tillage, planting times) create a constantly changing environment, preventing any single weed species from dominating.
    - **Smothers Weeds-**Certain crops, especially cover crops, can outcompete and suppress weed growth.
4. **Reduces Soil Erosion**
    - **Increased Ground Cover-**Rotations often include cover crops or crops that provide good ground cover, protecting the soil from wind and water erosion, especially during fallow periods.
    - **Improved Soil Structure-**Healthy soil with good aggregation is less susceptible to erosion.
5. **Optimizes Water Use**
    - Different crops have varying water requirements and root depths, allowing for more efficient use of available soil moisture.
6. **Diversifies Farm Income and Reduces Risk**
    - Growing multiple crops diversifies income streams, making the farm less vulnerable to market fluctuations or the failure of a single crop.
    - Spreads out labor needs throughout the year as different crops have different planting, management, and harvest times.

Common Crop Rotation Strategies/Examples

While specific rotations depend on climate, soil type, and farm goals, common strategies often involve grouping crops by their characteristics:

- **By Plant Family-**This is very common to avoid specific pest/disease buildup. For example:
    - **Legumes (Nitrogen-fixers)-**Beans, peas, clover, alfalfa.
    - **Brassicas/Cole Crops (Heavy feeders)-**Cabbage, broccoli, kale, mustard.
    - **Root Vegetables-**Carrots, potatoes, sweet potatoes, radishes.
    - **Fruiting Vegetables-**Tomatoes, peppers, squash
    - **Leafy Greens-**Lettuce, spinach, chard.
- **By Nutrient Requirements-**Alternating between nitrogen-fixing crops, heavy feeders, and crops with moderate needs.
- **By Rooting Depth-**Mixing deep-rooted crops with shallow-rooted ones to utilize nutrients at different soil levels and improve soil structure throughout the profile.
- **Including Cover Crops-**Planting non-cash crops (e.g., lab-lab) during off-seasons to protect soil, add organic matter, suppress weeds, and fix nitrogen.
- **Typical Rotations (Examples):**
    - **Simple 2-Year:** Maize - Soybeans

- **3-Year:** Legume (e.g., beans) - Heavy Feeder (e.g., maize) - Root Crop (e.g., potatoes)
- **4-Year**
    - ✓ 1st year, Maize, Staple food (heavy feeder)
    - ✓ 2nd year, Lablab / Cowpeas, Soil building (nitrogen fixation, green manure)
    - ✓ 3rd year, Sweet Potatoes / Groundnuts, Food security, breaks soil pan, pest cycle break
    - ✓ 4th year, Mixed Vegetables, Cash crop, utilises high fertility

Implementing Crop Rotation

1. **Assess Your Land-**Understand your soil type, drainage, sun exposure, and historical crop performance in different areas.
2. **Divide Your Growing Area-**Break your farm or garden into distinct plots.
3. **Categorize Your Crops-**Group the crops you plan to grow by their families, nutrient needs, and other relevant characteristics.
4. **Plan the Sequence-**Design a multi-year rotation plan for each section, ensuring that crops from the same family or with similar needs do not follow each other in consecutive seasons. Allow for at least a 3-4 year gap before planting the same crop family in the same plot/field.
5. **Incorporate Cover Crops-**Integrate cover crops into your rotation, especially during fallow periods, to enhance soil health.
6. **Keep Records-**Maintain detailed records of what was planted where, when, and any observations about pests, diseases, or soil health. This helps in refining your rotation plan over time.
7. **Be Flexible-**Adapt your plan based on unforeseen circumstances (e.g., weather, market demands, and unexpected pest outbreaks).

3. Mulching

Mulching is an agriculture practice that involves applying a layer of material, known as mulch, to the surface of the soil. This layer acts as a protective blanket for the soil, mimicking the natural process that occurs on forest floors where fallen leaves and organic matter cover the ground.

How Mulching Works

The mulch layer shields the soil from direct sunlight and wind, which are primary causes of water loss. It also creates a barrier that suppresses weed growth, regulates soil temperature, and, in the case of organic mulches, gradually enriches the soil as it decomposes.

Key Benefits of Mulching

1. **Water Conservation-**This is one of the most critical benefits, especially in warmer climates or during dry seasons. Mulch significantly reduces water evaporation from the soil surface, meaning plants need less frequent watering. Studies have shown that mulching can reduce soil evaporation by up to 50% and irrigation needs by up to 30%.
2. **Weed Suppression-**By blocking sunlight, mulch prevents weed seeds from germinating and growing. This saves time and effort spent on weeding and reduces competition for water and nutrients between weeds and desired plants.
3. **Soil Health Improvement-**Organic mulches (like compost or wood chips) break down over time, adding valuable organic matter to the soil. This improves soil structure, increases its water-holding capacity, and provides a slow-release source of nutrients for plants.
4. **Temperature Regulation-**Mulch insulates the soil, keeping it cooler in the summer and warmer in the winter. This protects plant roots from extreme temperature fluctuations and helps create a more stable environment for beneficial soil organisms.
5. **Erosion Control-**The mulch layer acts as a physical barrier that protects the soil from the impact of heavy rain and wind. It slows down water runoff, allowing it to infiltrate the soil more effectively and preventing the loss of topsoil and nutrients.
6. **Pest and Disease Management-**A layer of mulch can act as a barrier to some soil-borne pests and diseases. It also prevents the splashing of soil onto lower leaves of plants during irrigation or rain, which can spread pathogens.

Types of Mulch

Mulches are generally categorized into two main groups:

1. Organic Mulches These are made from natural, biodegradable materials, and they offer the added benefit of enriching the soil as they decompose. They need to be replenished periodically, typically annually.

- **Wood Chips/Shredded Bark:** Excellent for long-term use around trees, shrubs, and in permanent garden beds. They break down slowly and are good at suppressing weeds.
- **Compost:** A nutrient-rich mulch that actively improves soil fertility and structure, it is ideal for vegetable gardens and annual flower beds.
- **Straw/Hay:** Lightweight and effective for mulching vegetable gardens, especially around new plantings. Straw is generally preferred as it is less likely to contain weed seeds than hay.
- **Grass Cuttings:** Readily available and a good source of nitrogen. They should be applied in thin layers to prevent them from becoming matted and smelly, which can restrict air and water flow.
- **Shredded Leaves:** An excellent and free local resource. They improve soil structure and are a favorite of earthworms.

2. Inorganic Mulches These materials do not decompose and are primarily used for their durability, weed control, and decorative purposes. They do not add nutrients or organic matter to the soil.

- **Gravel/Stone-**Often used in landscaping for decorative purposes or in areas where a permanent, low-maintenance solution is desired, such as around succulents or in pathways. They can absorb and radiate heat, which may not be suitable for all plants.
- **Plastic Mulch-**Used in commercial agriculture to warm the soil early in the season, conserve moisture, and control weeds. However, it can prevent water from reaching the soil and does not improve soil health.
- **Landscape Fabric-**A woven material that allows water and air to pass through while suppressing weeds. It is often covered with a layer of organic or stone mulch for aesthetic purposes.

How to Apply Mulch

1. **Prepare the Area-**First, remove all existing weeds from the area to be mulched and if the soil is dry, water it thoroughly.
2. **Apply the Mulch-**Spread a layer of mulch evenly over the soil surface.
3. **Maintain Proper Depth-**A general rule of thumb is to apply organic mulch at a depth of 5 to 10 cm. If the layer is too thin, weeds will grow through it; if it is too thick, it can suffocate the soil and roots.
4. **Keep it Away from Stems-**Leave a small gap (a few centimeters) between the mulch and the base of plant stems or tree trunks. Piling mulch directly against the plant can trap moisture, leading to rot, disease, and creating a habitat for pests.

4. Green Manuring

It is a cornerstone of sustainable and organic farming, aiming to mimic natural ecosystem processes to build healthy soil. Green manuring is an agricultural practice that involves growing specific crops, often referred to as ***green manure crops or cover crops***, for the sole purpose of incorporating them back into the soil while they are still green and succulent. This process enhances soil fertility, structure, and overall health.

How Green Manuring Works

The process typically involves:

1. **Planting-**Green manure seeds are planted on a piece of land that would otherwise be fallow, or between main cash crops in a rotation.

2. **Growth-**The green manure crop absorbs nutrients from the soil, adding organic matter, and, in the case of legumes, fixing atmospheric nitrogen. Their roots also help to break up compacted soil.
3. **Incorporation-**Before the green manure crop flowers or produce to seed (to prevent them from becoming weeds themselves), it is either mowed, chopped, or ploughed directly into the soil. This can be done with simple hand tools in small gardens or with machinery on larger farms.
4. **Decomposition-**Once incorporated, the plant material decomposes, and releasing stored nutrients back into the soil in an easily available form for subsequent crops. The decaying organic matter also feeds beneficial soil microorganisms, further enhancing soil life.

Key Benefits of Green Manuring

Green manuring offers a multitude of benefits for soil and crop production:

1. **Enriches Soil Fertility**
    - **Nitrogen Fixation:** Leguminous green manures (e.g., sunnhemp) have a symbiotic relationship with nitrogen-fixing bacteria (*Rhizobia*) in their root nodules. These bacteria convert atmospheric nitrogen into a form usable by plants, effectively adding free nitrogen to the soil.
    - **Nutrient Cycling:** Non-leguminous green manures (e.g., rye, mustard) scavenge leftover nutrients from the soil profile that might otherwise leach away, particularly during rainy seasons. When incorporated, these nutrients are made available to the next crop.
    - **Increased Organic Matter:** The biomass from green manure crops adds significant organic matter to the soil upon decomposition. Organic matter improves soil structure, aeration, drainage, and water retention capacity.
2. **Improves Soil Structure**
    - The extensive root systems of green manure crops penetrate and break up compacted soil, creating channels for air and water. This makes it easier for subsequent crop roots to grow.
    - The added organic matter binds soil particles together, forming stable aggregates, which improves overall soil structure.
3. **Suppresses Weeds**
    - Fast-growing green manures quickly cover the soil surface, shading out and outcompeting weed seedlings for light, water, and nutrients.
    - Some green manure crops (e.g., rye) release allelopathic compounds that inhibit weed seed germination.
    - The act of incorporating the green manure also disrupts weed growth.
4. **Reduces Soil Erosion**
    - By providing a living cover, green manures protect bare soil from the erosive forces of wind and rain, especially during off-seasons or fallow periods.
    - Improved soil structure also makes the soil more resistant to erosion.

5. **Manages Pests and Diseases**
    - Breaking the life cycles of specific pests and diseases that might target cash crops by introducing a non-host plant into the rotation.
    - Some green manures (e.g., certain mustards) can act as biofumigants, suppressing soil-borne pathogens and nematodes.
    - They can also attract beneficial insects.
6. **Optimizes Water Use**
    - Improved soil structure and increased organic matter enhance the soil's ability to absorb and retain moisture, reducing the need for irrigation.

Types of Green Manure Crops

Green manure crops are generally divided into three main categories:

1. **Legumes:** (Nitrogen-fixers)
    - **Peas** (e.g., Field peas): Fast-growing, good for short rotations.
    - **Beans** (e.g., Faba beans, Cowpea, Lablab): Good for nitrogen fixation and biomass production, especially in warmer climates.
    - **Sunn Hemp (*Crotalaria juncea*):** Fast-growing, tropical legume providing high biomass and nitrogen.
2. **Grasses:** (Biomass producers, nutrient scavengers, good for soil structure)
    - **Rye** (e.g., Winter rye, Annual ryegrass): Excellent for suppressing weeds and preventing nutrient leaching, especially in winter.
    - **Oats:** Good for building organic matter.
    - **Barley:** Similar to oats, good for biomass.
3. **Brassicas and Other Broadleaves:** (Weed suppressors, break up hardpans, some bio fumigant properties)
    - **Mustard** (e.g., White mustard, Brown mustard): Fast-growing, good for weed suppression and some have biofumigant qualities.
    - **Radish** (e.g., Daikon radish, Fodder radish): Deep taproots break up compacted soil (hardpans).
    - **Buckwheat** Very fast-growing, good for short rotations, attracts pollinators, and can make phosphorus more available.
    - **Phacelia** Attracts beneficial insects, good biomass producer.

Often, mixtures of different green manure types are used to gain a wider range of benefits.

Implementing Green Manuring

1. **Choose the Right Crop:** Select a green manure crop based on your climate, soil type, the needs of your subsequent cash crop, and the specific problem you want to address (e.g., nitrogen deficiency, compaction, weeds).
2. **Timing of Sowing:** Sow green manure seeds when the land would otherwise be bare – typically after harvest, in spring before planting, or during fallow periods between crops.
3. **Preparation:** Prepare a relatively fine seedbed, similar to what you would for a cash crop, to ensure good germination.
4. **Sowing Method:** Seeds can be broadcast by hand or sown with a seed planter.
5. **Incorporation Timing:** The most critical step. Green manures should generally be incorporated into the soil when they are young, succulent, and actively growing, often just before or at the onset of flowering. At this stage, their carbon-to-nitrogen (C:N) ratio is low, meaning they decompose quickly and release nutrients readily. If left to mature too much, they become woody, decompose slowly, and can temporarily tie up nitrogen.
6. **Incorporation Method:**
   - **Ploughing under:** The most common method, thoroughly mixing the green manure into the topsoil.
   - **Mowing/Chopping:** For minimum tillage systems, the green manure can be mowed or chopped and left on the surface as a mulch, gradually decomposing.
   - **Rolling:** For larger operations, specialized equipment can roll down the green manure, forming a dense mulch layer.
7. **Decomposition Period:** Allow adequate time, typically 2-4 weeks, depending on climate and material, for the green manure to decompose before planting your next cash crop. This prevents potential nitrogen drawdown (where microbes consume available nitrogen to break down the carbon-rich plant material, temporarily depriving the next crop).

5. Agroforestry

Agroforestry is a dynamic and integrated land-use system that intentionally combines trees and shrubs with agricultural crops and/or livestock on the same unit of land. It's not just about planting trees on a farm; it's about managing the interactions between these components to create a more productive, sustainable, and resilient ecosystem. This ancient practice, increasingly recognized for its modern benefits, mirrors natural forest ecosystems in its multi-layered structure and functional diversity.

The essence of agroforestry lies in its "3D farming" approach, where the different components interact both above and below ground, leveraging the unique benefits each provides.

Key Principles of Agroforestry

- **Intentionality:** The combination of trees, crops, and/or livestock is planned and managed as a cohesive system.
- **Intensity:** The system is managed to optimize productivity of all components, often aiming for higher yields per unit area than monoculture systems.
- **Interaction:** There are beneficial ecological and economic interactions between the different components (e.g., trees providing shade, improving soil, or diversifying income).
- **Integration:** The elements are integrated to form a synergistic whole, maximizing their combined potential.

Benefits of Agroforestry:

Agroforestry offers a wide array of environmental, economic, and social advantages:

Environmental Benefits:

1. **Improved Soil Health:**
    - **Increased Organic Matter:** Falling leaves, branches, and root decomposition from trees add significant organic matter to the soil, improving its structure, water retention, and nutrient-holding capacity.
    - **Nutrient Cycling:** Deep-rooted trees can access nutrients from deeper soil layers that are unavailable to shallow-rooted annual crops, bringing them to the surface through leaf litter and root exudates, thereby enriching the topsoil.
    - **Erosion Control:** Tree roots bind the soil, dramatically reducing erosion from wind and water. The tree canopy also intercepts rainfall, reducing its impact on the soil surface.
2. **Biodiversity Enhancement:** Agroforestry systems create more complex habitats than conventional monocultures, supporting a wider variety of plants, animals (including pollinators and beneficial insects), and microbial life. This increased biodiversity contributes to more stable and resilient ecosystems.
3. **Water Quality Improvement:** Riparian (streamside) buffer strips of trees and shrubs filter runoff from agricultural fields, preventing excess nutrients and pollutants from entering waterways. Trees also improve water infiltration into the soil, reducing surface runoff.
4. **Climate Change Mitigation and Adaptation:**
    - **Carbon Sequestration:** Trees capture carbon dioxide from the atmosphere and store it in their biomass (trunks, branches, roots) and in the soil, acting as carbon sinks and helping to mitigate climate change.
    - **Microclimate Regulation:** Trees provide shade, reducing soil temperature and evapotranspiration for understory crops and livestock. They also act as windbreaks, protecting crops and animals from harsh winds, thereby improving microclimates and making systems more resilient to extreme weather.

Economic Benefits:

1. **Diversified Income Streams:** Farmers can derive income from multiple products (e.g., timber, fruits, nuts, fodder, medicinal plants, fuelwood, livestock products) from the same land unit, reducing reliance on a single crop and mitigating risk from market fluctuations or crop failure.
2. **Increased Productivity:** Often, the combined yield of trees and crops in an agroforestry system can be higher than monoculture yields of either component grown separately, as they utilize resources (light, water, nutrients) more efficiently.
3. **Reduced Input Costs:** Improved soil fertility from nitrogen-fixing trees and increased organic matter can reduce the need for synthetic fertilizers. Enhanced pest control by beneficial insects attracted to diversified systems can reduce pesticide use.
4. **Higher Value Products:** Some agroforestry practices focus on specialty crops that command higher market prices.
5. **Long-term Investment:** Trees represent a long-term asset that can appreciate in value, providing future income from timber or other tree products.

Social Benefits:

1. **Food Security:** Diversified production contributes to a more stable and varied food supply for communities.
2. **Improved Livelihoods:** Increased and sustained productivity can lead to higher incomes and improved living standards for farmers and rural communities.
3. **Community Resilience:** Agroforestry systems can make communities more resilient to environmental shocks and economic changes.
4. **Cultural Preservation:** Many traditional farming systems around the world already incorporate agroforestry principles, and modern agroforestry can help preserve these valuable cultural practices.

Common Agroforestry Practices/Systems:

1. **Silvopasture:** The integration of trees, forage, and livestock on the same land. Trees provide shade and shelter for animals, improve forage quality, and offer timber or fruit income. Livestock can help manage understory vegetation.
2. **Alley Cropping:** Agricultural crops are grown in alleys between rows of widely spaced trees or shrubs. The trees can provide windbreaks, improve nutrient cycling, and yield additional products (e.g., nuts, fruits, timber).
3. **Riparian Forest Buffers:** Strips of trees, shrubs, and grasses planted along the edges of rivers, streams, and other waterways. They filter pollutants from agricultural runoff, stabilize streambanks, reduce erosion, and provide wildlife habitat.
4. **Windbreaks/Shelterbelts:** Linear plantings of trees and shrubs designed to reduce wind speed across open fields. They protect crops, livestock, and farm

infrastructure from wind damage, reduce soil erosion, and can improve crop yields.

5. **Forest Farming:** Cultivating high-value, shade-tolerant specialty crops (e.g., medicinal plants, mushrooms, decorative ferns) under the canopy of an existing or newly planted forest.
6. **Home gardens:** Multi-layered systems, often around homesteads, that combine a diverse array of trees, shrubs, vegetables, and sometimes small livestock to produce food, fuel, and other products for household consumption and sale.

6. Conservation Agriculture

Conservation Agriculture (CA) is a sustainable farming system that aims to protect and regenerate soil resources while ensuring profitable and high-yielding crop production. It is a set of practices designed to minimize disturbance to the soil, maintain a permanent cover on the soil surface, and diversify crop species over time. This approach moves away from traditional intensive tillage practices that can lead to soil degradation, erosion, and reduced fertility.

The Three Core Principles of Conservation Agriculture:

CA is built upon three interconnected and mutually reinforcing principles:

1. **Minimum Tillage):**
   - This is the most defining feature of CA. It means avoiding conventional plowing, disking, or harrowing, which disrupt soil structure, expose organic matter to oxidation, and can lead to erosion.
   - Instead, planting is done directly into the un-tilled soil, often using specialized direct-seeding equipment that creates minimal disturbance (e.g., a narrow slit for seed placement).
   - The aim is to preserve the soil's natural structure, its network of pores and channels created by roots and soil organisms, and its biological activity.
2. **Permanent Soil Cover:**
   - The soil surface should always be covered by crop residues (leftovers from previous harvests) and/or living plants (cover crops).
   - This cover acts as a protective blanket, shielding the soil from the direct impact of rain and wind, reducing evaporation, and moderating soil temperature fluctuations.
   - As the organic matter decomposes, it feeds soil microbes, improves soil structure, and slowly releases nutrients, mimicking natural ecosystem processes.
3. **Diversified Crop Rotations:**
   - This involves growing different types of crops sequentially on the same land over several seasons or years, and often includes intercropping (growing multiple crops simultaneously).

    - Diversification breaks the life cycles of pests and diseases, optimizes the use of different soil depths for nutrient uptake (through varied root systems), and contributes diverse organic matter to the soil.
    - Including legumes in the rotation helps fix atmospheric nitrogen, reducing the need for synthetic nitrogen fertilizers.

Benefits of Conservation Agriculture:

Adopting CA practices offers a wide range of benefits, making agricultural systems more resilient, productive, and environmentally friendly:

- **Environmental Benefits:**
    - **Reduced Soil Erosion:** The permanent soil cover and lack of tillage protect the soil from wind and water erosion, preventing the loss of valuable topsoil.
    - **Improved Soil Health and Fertility:** Increased organic matter from residues and diverse roots enhances soil structure, aggregation, water infiltration, and nutrient cycling. This supports a healthier and more diverse community of soil organisms.
    - **Water Conservation:** Reduced evaporation from the soil surface due to mulching, combined with improved infiltration and water-holding capacity, significantly conserves soil moisture, making crops more resilient to drought.
    - **Climate Change Mitigation:** CA leads to increased carbon sequestration in the soil, removing $CO2$ from the atmosphere. Reduced fuel consumption from less tillage also lowers greenhouse gas emissions.
    - **Enhanced Biodiversity:** Creates a more diverse habitat for beneficial insects, earthworms, and microorganisms both above and below ground.
    - **Reduced Pollution:** Less soil erosion means reduced runoff of sediments, nutrients, and agrochemicals into waterways, improving water quality.
- **Economic Benefits:**
    - **Reduced Production Costs:** Eliminates or significantly reduces fuel, labor, and machinery costs associated with tillage operations. Over time, it can also reduce the need for synthetic fertilizers and pesticides.
    - **Increased and More Stable Yields:** While initial yields might sometimes be comparable, CA often leads to higher and more stable yields over the long term due to improved soil health and greater resilience to adverse weather conditions.
    - **Improved Farm Profitability:** Lower input costs combined with stable or increased yields can lead to higher net profits for farmers.
    - **Better Use of Labor:** Redistributes labor needs, reducing peak labor demands often associated with plowing and planting.
- **Agronomic Benefits:**
    - **Improved Root Development:** Undisturbed soil allows for more continuous root growth and better access to water and nutrients.

    - **Better Nutrient Use Efficiency:** Healthier soil and improved microbial activity make nutrients more available to plants.
    - **Weed Management:** While challenges exist, effective CA systems can suppress weeds over time through permanent cover and diverse rotations.

Challenges of Implementing Conservation Agriculture:

Despite its numerous benefits, the adoption of CA can face several challenges, particularly for smallholder farmers:

- **Initial Investment:** Specialized direct-seeding equipment can be expensive, posing a barrier for farmers with limited capital.
- **Weed Management:** In the initial transition phase, weed pressure might increase without tillage. This can necessitate reliance on herbicides (which may contradict organic principles) or increased manual weeding, which can be labor-intensive.
- **Residue Management:**
    - Competing uses for crop residues (e.g., livestock feed, fuel, building materials) can make it difficult for farmers to leave enough cover on the soil.
    - Pest issues can sometimes arise if residues harbor certain pests.
- **Technical Knowledge and Training:** Farmers need training and technical support to understand the principles and apply CA practices effectively, as it requires a different mindset and management approach than conventional farming.
- **Cultural Resistance:** Traditional farming practices are deeply ingrained, and shifting away from tillage can face resistance due to cultural norms and beliefs about what "clean" farming looks like.
- **Pest and Disease Dynamics:** While diversity can help, specific pests or diseases might thrive in undisturbed soil or residue-covered environments, requiring careful management.
- **Transition Period:** It can take several seasons for the full benefits of CA to become apparent as the soil regenerates. Farmers may experience a temporary dip in yields or increased management challenges during this transition.

7. SOIL TESTING

Soil testing is a process of analyzing soil samples to determine their chemical, physical, and biological properties. It is typically done to assess soil fertility and predict nutrient deficiencies, helping to guide decisions about fertilisation and other soil management practices.

Here are some key aspects of what a soil test involves:

- ✓ **Determining Nutrient Levels:** Soil tests measure the amounts of essential plant nutrients like nitrogen (N), phosphorus (P), and potassium (K), as well as micronutrients.
- ✓ **Measuring pH:** The test indicates whether the soil is acidic, alkaline, or neutral, which is crucial as pH affects nutrient availability.
- ✓ **Analyzing Soil Composition:** It can reveal the proportions of sand, silt, and clay in the soil, which influences water retention and drainage.
- ✓ **Assessing Organic Matter:** The amount of organic matter in the soil is a key indicator of its health and ability to retain nutrients, moisture and sustain microbial life.
- ✓ **Detecting Potential Contaminants:** In some cases, soil tests can also identify the presence of heavy metals or other pollutants.

By understanding these properties, farmers, can make informed choices to improve soil health and optimize plant growth.

Key steps in soil testing

1. **Planning and Preparation:**

    - ➢ **Define the area to be tested:** Decide which specific area or field you want to test. If the area is large or has different fertility levels (e.g., based on topography, previous use), you might need to take separate samples.
    - ➢ **Tools:** You will need a hoe, spade or trowel, a clean plastic bucket, and clean sample bags.
    - ➢ **Sampling depth:** For general fertility, a depth of about 15-30 cm is common for agricultural fields.
    - ➢ **Soil Sample Collection:**

        - ✓ **Take multiple samples:** To get a representative sample of the entire area, collect multiple subsamples from different spots within the defined area. A common recommendation is to take a sample every 15 steps for a uniform area, using a zigzag or W pattern.

- ✓ **Remove surface debris:** Clear away any leaves, thatch, or other debris from the soil surface at each sampling point.
- ✓ **Collect the soil sample:** Depending on which tool used, dig a small hole and take a sample of soil from the inside of the hole at the desired depth.
- ✓ **Combine the subsamples:** Place all the collected subsamples into the clean plastic bucket and mix them thoroughly to create a composite sample. This ensures that the sample sent to the lab represents the average condition of the area.

2. **Sample Preparation and Submission:**

- ➢ **Air dry (if required):** Some labs may require you to air dry the soil sample before sending it in. Check the specific instructions of the lab you will be using. (This is normally done at The Soil Testing Laboratory)
- ➢ **Fill the sample bag:** Take a representative portion of the mixed soil from the bucket and place it in a clean, labeled sample bag. Do not use bread bags or any bag that was used to carry food items
- ➢ **Label clearly:** Label each sample bag with your name, address, the date, your RDA, crop produced, size of your field and a clear identifier for the sampling area (e.g., ***Insimu yemantongomane***) Alphabets or numbers can also be used.
- ➢ **Send to the laboratory:** Submit the sample to your nearest R. D. A., Soil Testing Unit Laboratory or Extension Officer.

3. **Laboratory Analysis:**

- ➢ Typically a laboratory performs various chemical, physical, and sometimes biological tests on your soil sample, depending on what you requested. Common tests include pH, nutrient levels (nitrogen, phosphorus, potassium, calcium, magnesium, etc.), organic matter content, and salinity.

4. **Interpretation of Results:**

- ➢ Once the analysis is complete, the lab will send you a report with the results. This report will often include an interpretation of the results, indicating whether the levels of certain nutrients are low, adequate, or high.

5. **Recommendations:**

   - Based on the soil test results and the information you provided about your intended use for the land (e.g., specific crops), the lab will usually provide recommendations for the type and amount of fertilizers or soil amendments (like lime or gypsum) needed to optimize soil fertility and plant growth.

By following these steps, you can get valuable information about your soil and make informed decisions to manage it effectively. Remember that proper sampling is crucial for accurate results.

7. Lime Application

Lime application, also known as liming, is a crucial agricultural practice involving the addition of liming materials to soil. Its primary purpose is to neutralize soil acidity, a common issue that can hinder crop growth and nutrient availability.

Why is Lime Application Important?

- **Neutralizes Soil Acidity:** Many soils are naturally acidic due to factors like high rainfall, crop removal of minerals, and the use of certain chemical fertilizers. Lime raises the soil's pH, making it more neutral or slightly alkaline, which is ideal for most crops.
- **Enhances Nutrient Availability:** When soil is acidic, essential nutrients like phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) become "locked up" and less available to plants. Liming unlocks these nutrients, improving their uptake by crops and enhancing fertilizer efficiency.
- **Improves Soil Structure:** Lime promotes better soil aggregation, especially in clay soils, leading to improved drainage, aeration, and root development. This results in healthier plants and better water penetration.
- **Reduces Toxicity:** Acidic soils can increase the solubility of toxic elements like aluminum (Al) and manganese (Mn), which can harm plant growth. Lime application reduces the availability of these toxic substances.
- **Boosts Microbial Activity:** Many beneficial soil microorganisms that contribute to nutrient cycling and organic matter decomposition thrive in neutral to slightly alkaline pH levels. Liming creates a more favorable environment for these microbes, enhancing soil fertility.

- **Provides Essential Nutrients:** Liming materials directly supply calcium and, in some cases, magnesium, which are vital macronutrients for plant growth and structure.

Types of Lime Used in Agriculture:

Various types of liming materials are available, differing in their chemical composition and reactivity:

- **Dolomitic lime** which is derived from **dolomitic limestone** , that primarily consists of the mineral **dolomite**. Chemically, dolomite is **calcium magnesium carbonate** ($CaMg(CO_3)_2$)
- **Agricultural Lime (Calcitic lime):** This is the most commonly used type. It's made from crushed limestone (calcium carbonate, $CaCO_3$) and is effective for neutralizing acidity and supplying calcium. Dolomitic lime is a type of agricultural lime that also contains magnesium carbonate ($MgCO_3$), making it suitable for soils deficient in magnesium.
- **Burnt Lime (Quicklime):** This is calcium oxide (CaO), produced by heating limestone. It's a faster-acting and more concentrated form of lime but is caustic and less commonly used in general agriculture due to handling difficulties.
- **Hydrated Lime (Slaked Lime):** This is calcium hydroxide ($Ca(OH)_2$), made by treating burnt lime with water. It also acts quickly but is more expensive than agricultural lime.
- **Granulated Lime:** This is finely ground limestone formed into granules, making it easier to spread and reducing wind losses. It's fast-acting and often used for maintenance dressings where the pH is already good.
- **By-product Limes:** These can include lime kiln dust or cement kiln dust, which may offer good value but require checking their analysis for neutralizing value and nutrient content.

How to Apply Agricultural Lime:

- **Soil Testing is Crucial:** Always start with a soil test to determine the current pH level, the lime requirement, and any specific nutrient deficiencies. This ensures you apply the correct amount and type of lime.
- **Timing:** While lime can be applied year-round, late summer/autumn is often ideal as the ground is firm, and silage cuts may have been taken. Applying in early spring also works well, allowing the lime to react before the main growing season.
- **Application Methods:**
    - **Surface Application:** This is the most common method. The goal is even coverage across the field. Manual and/or mechanical spreaders can be used, making sure that the lime is evenly spread across the field
    - **Incorporation:** it is important to immideately incorporate lime in the soil for faster results and not to lose it with blowing wind. This can be achieved by using a tractor drawn rake or disc harrow

    - **Deep Placement/Direct Injection:** In cases of severe subsurface acidity, specialized machinery can be used to inject lime deeper into the soil profile. This is more complex and costly but can rapidly address deep acidity.
- **Considerations for Application:**
    - **Particle Size:** Finer lime particles react faster and raise pH more quickly, while larger particles provide a slower, more sustained effect.
    - **Weather:** Avoid applying lime in strong winds to minimize losses due to blowing dust. Wetting the lime can help with this.
    - **Interaction with other amendments:** If applying slurry or urea, apply them first and wait about 10 days before applying lime to avoid nitrogen loss. Conversely, if lime is spread first, wait three months before applying slurry or urea.
    - **Rates:** Application rates determined by a soil test

By carefully planning and executing lime application based on soil test results, farmers can significantly improve soil health, optimize nutrient utilization, and enhance crop productivity, leading to a more sustainable and profitable agricultural system.

8. Fertiliser Application

Fertilizer application is a critical practice in agriculture, aimed at supplementing natural soil nutrients to optimize crop growth and yield.

Importance of Fertilizer Application:

- **Addressing Nutrient Deficiencies:** Because of mono-cropping, soils often exhibit deficiencies in key nutrients such as Nitrogen (N), Phosphorus (P), Zinc (Zn), and others. Fertilizers directly supply these deficient elements, ensuring plants have access to what they need for healthy development.
- **Boosting Crop Yields:** Adequate nutrient supply is directly correlated with higher crop yields. Fertilizers enable plants to reach their full genetic potential, leading to increased productivity of staple crops like maize, as well as cash crops like sugarcane.
- **Improving Crop Quality:** Beyond quantity, fertilizers can enhance the quality of crops, including their nutritional content, size, and appearance.
- **Compensating for Nutrient Removal:** Each harvest removes a significant amount of nutrients from the soil. Fertilizers help replenish these removed nutrients, maintaining long-term soil fertility and productivity.
- **Enhancing Soil Fertility (when combined with good practices):** While inorganic fertilizers alone might not always improve soil organic matter, their judicious use, especially in conjunction with organic amendments (like kraal manure or compost), can significantly contribute to overall soil health and nutrient cycling.

Key Considerations for Fertilizer Application

1. **Soil Testing: The Foundation**
    - **Absolute Necessity:** Before applying any fertilizer, a comprehensive soil test is the most important step. This provides accurate information on the soil's current nutrient status, pH, organic matter content, and other crucial parameters.
    - **Local Services:** Farmers should utilise local soil testing services, such as those that are available through the Ministry of Agriculture, research institutions, or private agricultural service providers.
    - **Recommendation Basis:** Soil test results inform the type, amount, and timing of fertilizers required for specific crops and their targeted yields.
2. **Common Types of Fertilizers in Eswatini:**
    - **NPK Blends:** Compound fertilizers like 2:3:2 (commonly with zinc, e.g., 2:3:2 (22) + 0.5% Zn) or 2:3:4 are widely used, providing a balanced supply of nitrogen, phosphorus, and potassium. The numbers represent the percentage by weight of N, P_2O5, and K_2O, respectively.
    - **Straight fertilisers:** These are fertilizers that supply a single primary nutrient or a limited combination:
        1. **Urea (46% N):** A common source of nitrogen for top-dressing.
        2. **Limestone Ammonium Nitrate (LAN) (28% N):** Another popular nitrogen source (*makhabeni*)
        3. **MAP (Monoammonium Phosphate) and DAP (Diammonium Phosphate):** Good sources of both nitrogen and phosphorus.
        4. **Muriate of Potash (KCl - Potassium Chloride):** A common source of potassium.
        5. **SOP (Sulphate of Potash), TSSP (Triple Superphosphate), SSP (Single Superphosphate):** Other specialized sources of P and K.

        6**. Micronutrients:** Given the reported deficiencies, specific micronutrient fertilizers (e.g., zinc sulfate, manganese sulfate) or micronutrient-fortified NPK blends are also important.

        7. **Organic Fertilizers:** Kraal manure, broiler manure, compost, and other organic inputs are increasingly recognized for their role in improving soil structure, water retention, and microbial activity, complementing mineral fertilizers.

3. **Methods of Application:**
   - **Broadcasting:** *Spreading granular fertilizer uniformly over the entire field surface. This is simple but can lead to nutrient loss if not incorporated. It is often used for basal applications (before planting).*
   - **Banding:** Placing fertilizer in narrow bands or rows, typically near or beneath the seed row. This concentrates nutrients where plants need them most, improving uptake efficiency and reducing waste. Often used for basal application.
   - **Side-Dressing:** Applying fertilizer in a band beside the crop rows during the growing season. This provides nutrients when the crop's demand is highest (e.g., nitrogen for maize at knee-high stage).
   - **Foliar Feeding:** Applying liquid fertilizers directly to plant leaves.This provides a quick nutrient boost, especially for micronutrients, but is not a substitute for soil-applied fertilizers for macronutrients.
   - **Fertigation:** Applying liquid fertilizers through the irrigation system (e.g., drip irrigation). This is highly efficient as it delivers nutrients directly to the root zone.
   - **Pellet Application:** Used in specific contexts, like placing nitrogenous fertilizer pellets in paddy fields.
   - **Controlled-Release Fertilizers:** These fertilizers release nutrients over an extended period, reducing application frequency and minimizing leaching. They are suitable for crops with long growing seasons.
4. **Timing of Application:**
   - **Basal Application:** Applied before or at planting, often incorporated into the soil, to provide initial nutrients for seedling establishment (e.g., NPK blends).
   - **Top-Dressing:** Applied during the growing season when the crop has a high demand for specific nutrients (e.g., nitrogen for maize at key growth stages like knee-high or before tasseling).
   - **Split Application:** Dividing the total fertilizer requirement into multiple applications throughout the growing season. This matches nutrient availability with crop demand and minimizes losses.
   - **Crop-Specific Timing:**
     - **Maize:** Basal NPK application at planting, followed by nitrogen top-dressing (e.g., LAN or Urea) when plants are knee-high or at 2-6 weeks after planting for optimal growth and yield. Nitrogen, phosphorus, and potassium uptake peak during flowering.
     - **Sugarcane:** Nitrogen is crucial for early growth and tillering. Phosphorus is vital for root development at the start of the growing season. Potassium enhances sugar recovery and overall quality. Fertilizer application for sugarcane needs to be tailored to its long growth cycle and specific nutrient removal rates.
5. **Calculating Fertilizer Rates:**
   - Formula: The general formula for solid fertilizers is:

     [Fertilizer rate (kg/ha)] = [Recommended nutrient application rate (kg/ha)]/ [fertiliser nutrient content (%)/100]

   - Example (Maize in Eswatini): If a soil test recommends 80 kg N/ha, and you are using Urea (46% N):

Urea Application Rate= 80kgN/ha/(46/100) = 80kgN/ha/0.46 = **173.91≈174 kg Urea/ha**

- **P_2O5 and K_2O:** Remember that phosphorus and potassium concentrations on fertilizer labels are typically expressed as P_2O5 and K_2O, not elemental P and K. Soil test recommendations usually align with these oxide forms.

Environmental and Economic Considerations:

- **Nutrient Use Efficiency:** The goal is to maximize the amount of applied fertilizer taken up by the plant and minimize losses to the environment (leaching, runoff, and volatilisation). Proper timing, placement, and formulation contribute to higher efficiency.
- **Environmental Impact:** Over-application of fertilizers, particularly nitrogen and phosphorus, can lead to environmental issues such as water pollution (eutrophication of water bodies) and greenhouse gas emissions (from nitrogen fertilizers). Responsible application practices are crucial for sustainability in Eswatini.
- **Economic Viability:** Fertilizer is a significant input cost for farmers. Therefore, applying the right amount at the right time ensures a good return on investment and avoids unnecessary expenses.
- **Soil Health:** While mineral fertilizers provide essential nutrients, their long-term use without organic matter additions can sometimes lead to issues like increased soil acidity (which can be mitigated by liming). Combining inorganic and organic fertilizer application is often recommended for sustainable soil health.

By integrating soil testing, appropriate fertiliser types, precise application methods, and timely interventions, farmers can optimise fertiliser use for improved crop productivity and environmental stewardship.