Review Article

Soil Fertility: Factors Affecting Soil Fertility, and Biodiversity Responsible for Soil Fertility

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Abstract

Nutrient enriched soil is termed as “fertile”. A fertile soil maybe natural or inherent and it can be acquired by artificial fertilizers or manures. Fertility of soil can be affected by physical, chemical or biological factors ultimately having an impact on plant growth. Nutrients like nitrogen, phosphorous, sulfur as well as carbon etc. are not taken up by plants as it is but they have to be converted into their standard forms with help of microbes and nutrient cycling.

Effective management of soil nutrients is essential as it forms the basis of human existence. Fertilization supplements the soil with additional nutrients and improves soil quality, yield and profits. Soil animals play a vital part in soil structure creation by producing channels and pores, concentrating tiny soil particles into aggregates, and fragmenting and mixing organic substances throughout the soil. A positive relation between biodiversity of plants and soil fertility is observed.

This relation varies according to habitats, and biotic and abiotic factors. Soil fertility is crucial for agricultural productivity sustainability. Effective soil management is implemented to ensure high

productivity for economic viability and maintenance of soil fertility.

Keywords: Water retention capacity; Bulk density; Cation exchange capacity; Micronutrients; Macronutrients; Fertilizers; Manures

1. Soil Fertility

Capacity of soil to give the necessary substances in correct amounts to plants avoiding toxic concentration of any substance. So fertile soils have a leveled amount of nutrients which are enough to fulfil the requirements of plants. A fertile soil will contain all the nutrients required in greater amount i.e., nitrogen, phosphorus, potassium etc. and will also contain the nutrients required in smaller amount i.e., magnesium, molybdenum, iron, zinc etc.

Soil fertility and soil productivity are two different terms. Potential of soil to produce a definite yield of crops using some management system is soil productivity. Soil fertility has a great influence on soil productivity. A productive soil must be fertile but a fertile soil may or may not be productive [1].

2. Types of Soil Fertility [2]

2.1 Natural or Inherent fertility

The soil naturally contains all essential nutrients such as nitrogen, phosphorus etc. so this is natural or inherent fertility.

2.2 Acquired fertility

The soil has this type of fertility because artificial fertilizers, manures are applied to soil so that's why it is named as acquired fertility.

3. Characteristics of Fertile Soil [3]

Following are the characteristics of fertile soil.

- Contains all basic nutrients i.e., nitrogen, potassium and other minerals such as boron, iron, copper, zinc necessary for plant survival.
- Has a pH in the range of 6.0 to 6.8
- Has a large amount of topsoil
- Has a diversity of microbes which helps in plant growth
- Has organic matter which maintains the soil structure
- Has capacity to retain more moisture
- Has a depth that permits plants to grow their roots deep for nutrition
- High cation exchange capacity

4. Factors Affecting Soil Fertility [4]

4.1 Physical factors

- Climate
- Soil texture
- Soil structure
- Water retention capacity
- Electrical conductivity
- Bulk density

4.2 Chemical factors

- Soil pH
- Cation exchange capacity
- Plant nutrients (micronutrients, macronutrients)

4.3 Biological factors

- Organic matter
- Microorganisms

- Soil mineralogy
- Biogeochemical cycles

5. Physical Factors

5.1 Climate [4]

Weather conditions that exist in an area for long span is climate. Among features of climate, temperature and rainfall are the ones that affect the soil fertility. Crops yield obtained from fields depends on rainfall and temperature. Greenhouse gases have a great impact on climate which in turn has an effect on temperature and rainfall. Increased temperature and low rainfall have a bad impact on soil and they are involved in causing dry spell. Surface runoff and flooding is there if there is more rain in an area. So, both these factors have a bad impact on crop production and there will be less soil fertility.

Temperature impacts the presence of organic matter and also the working of microorganisms in soil. They do so by affecting the presence of plants or other herbs, shrubs. Places where temperature is high will have low presence of these and hence less organic matter.

5.2 Soil texture [4, 5]

Respective distribution of particle sizes in soil sample is considered as soil texture. On the basis of their sizes, these particles are divided as sand, silt and clay. Presence of pores, rate of breakdown of organic matter, solidity, cation exchange capacity, percolation, nutrient as well as water holding are influenced by soil texture so soil texture is much more significant while considering soil fertility.

5.3 Soil structure [4, 6]

Soil structure depends on the stable aggregates of soil particles. Soil aggregates are natural clusters of soil particles with strong binding force. These aggregates may be bound together with other aggregates in larger masses called peds. Cementing material is humus and polysaccharides produced by microbes. Fungi has greatest aggregating influence then streptomyces then gum producing bacteria and then yeast. Among fungi rapidly growing *Rhizopus*, *Mucor*, *Fusarium*, *Cladosporium*, *Aspergillus*, *Rhizoctonia* secrete gums. Gum producing bacteria are *Azotobacter*, *Rhizobium*, *Xanthomonas*, *Bacillus*. Soil structure is one of those properties which have a great impact on soil fertility.

Organic matter and farming patterns influence soil structure. Soil receiving well decomposed organic manures will have better soil aggregates. Activity of microbes helps in improving soil structure. Soil structure influences the movement of water and air in soil and organizational steadiness of soil. So, a soil with good structure will be stable and will be repellent of scraping away of soil. A good soil structure is grain-like with a diameter less than 0.5cm.

5.4 Water retention capacity [4]

Water holding or water retention capacity is the potential of soil to hold water against gravitational force. It is also known as the amount of water held by capillary spaces of soil after the percolation of gravitational water into deeper layers. Cohesion is involved in holding water molecules together. The soil sample in which sand dominates will have less water holding capacity. Gravitational, capillary and hygroscopic are three divisions of soil water.

This is an important factor to be considered in choosing which plants should be grown and to determine how much water to apply by irrigation. Availability of water in soil is a good indicator of soil fertility and it helps plant root to reach great depths. Organic matter content and soil texture, soil structure and bulk density influence water holding capacity.

5.5 Electrical conductivity [4-6]

Electrical conductivity is the measurement of total salt concentration in soil. The unit in which electrical conductivity is often measured is Deci-siemens/m (ds/m). Electrical conductivity of saline soils is more than 4ds/m and sodic soils is less than 4ds/m. Mostly Ca, Mg, K and Na salts are there in saline soils. The factors which are involved in developing saline soils are the accumulation of soluble salts, poor passage of water, water of irrigation, flood water, marine sedimentation and evapotranspiration. Soil fertility is indirectly measured in terms of electrical conductivity. Vegetation is influenced by high concentration of salt and also exchangeable sodium percentage affects it badly. Such soils are not good for plant growth and have low fertility.

5.6 Bulk density [4, 6]

Soil compaction is measured in terms of bulk density. It is obtained by the division of dry weight of soil to its volume (volume of particles and volume of spaces between particles). It is measured in g/cm^3.Soils in which sand dominate has a high bulk density and soils in which silt and clay dominate has a low bulk density. Bulk density is determined mainly by soil compaction. More compact soils have low spaces and high bulk density and those that are less compact and have enough pore spaces have low bulk density. High bulk density means poor passage of water through soil, poor exchange of gases or air and poor puncturing of roots to depth. Although these soils will not be easily moved by some external force. Water holding capacity, spaces between particles and other properties can be estimated from bulk density. Bulk density more than 1.6 g/cm^3 is not good for root growth and water movement. Soil texture and structure influence bulk density.

6. Chemical Factors

Soil fertility may depend on certain chemical factors as well. These chemical factors include concentration of nitrogen, cation, anion concentration, ion exchange reactions etc.

6.1 Soil pH

Soil pH is very important factor for soil fertility to determine the soil reactions and processes and it is indicated as the acidity and the alkalinity of the soil through measuring on pH scale from 0 to 14; pH 7 is considered neutral, pH lower than 7 is counted acidic and above 7 is considered alkaline. Majority of the plants are tolerant and they maintain pH range between 5.5-6.5. The solubility of most minerals and nutrients are higher in acidic soils than in slightly alkaline or neutral soils. The availability of macronutrients such as Ca, Mg, K, P, N, S, Mo and B in strongly acidic soil is reduced. Unlikely, the availability of micronutrients such as Fe, Mn, Zn, Cu and Co is more in soil with low pH.

6.2 Cation exchange capacity

It is the sum of total exchangeable cations that a soil can adsorb. It is a measure of soil fertility, nutrient retention capacity and the capacity to protect groundwater from cation contamination. It buffers fluctuations in the nutrient availability and soil pH. Clay and organic matter are the main sources of cation exchange capacity. The amount of clay and organic matter is directly proportional to cation exchange capacity and the potential fertility of the soil. Soils with higher value of sand may generally have higher CEC values, although the type of clay can visibly affect CEC. They hold few nutrients and then lose them so easily as soon as water moves through them. The coating of clay and organic matter on the sand particles make the soil's nutrient holding capacity. The cation exchange capacity of soil is directly proportional to the amount of nutrients it can hold and so the higher will be its fertility level.

6.3 Plant nutrients

Plants require water, air, light, suitable temperature, and 18 essential nutrients to survive. They all are needed in different quantities but each of them is equally important for the plant. They are classified into two groups:

- Macronutrients
- Micronutrients

6.3.1 Macronutrients: They are demanded in higher quantities and have two subgroups:

- Primary: This group includes Nitrogen (N), Phosphorus (P), Potassium (K). They are usually required in a crop fertilization process and also termed as fertilizers.

- Secondary: This group includes Calcium (Ca), Magnesium (Mg), Sulfur (S).These are normally needed in lesser amounts then the primary ones. They are also important to crop fertilization due to more stringent clean air standards and efforts to improve the environment.

6.3.1.1 Role of macronutrients in plant growth:

- Nitrogen for chlorophyll
- Protein's formation
- Phosphorus for photosynthesis
- Potassium for enzyme activity, starch formation, sugar formation
- Calcium for cell growth, component of cell wall
- Magnesium for enzyme activation
- Sulfur for amino acids and protein formation

6.3.2 Micronutrients: These are the nutrients that are needed in lesser or trace amounts but are as important as macronutrients. Other than the following, carbon, hydrogen and oxygen that make up the bulk of the plant weight are also important. They include; Iron (Fe), Manganese (Mn), Boron (B), Zinc (Zn), Copper (Cu), Molybdenum (Mo), Chloride (Cl), Sodium (Na), Nickel (Ni), Silicon (Si), Cobalt (Co) and Selenium (Se).

6.3.2.1 Role of micronutrients in plant growth:

- Boron for reproduction
- Chlorine for root growth
- Copper for enzyme activation
- Iron for photosynthesis
- Manganese for enzyme activation
- Sodium for water movement
- Zinc for enzymes and auxins component

- Molybdenum for Nitrogen fixation
- Nickel for Nitrogen liberation
- Cobalt for Nitrogen fixation
- Silicon for cell wall toughening

6.3.2.2 Deficiency: Their deficiency can cause the retarded plant growth, infertile soil, yellow leaves and even plant death. Therefore, the proper nutrition provision is really necessary for the plant's proper growth. The plant in the absence of any factor will grow only to the point where the factor is no longer limiting factor and that's why the excessive provision of nutrients beyond this limit is useless.

7. Biological Factors

Biologically important factors are the living components required for improved soil fertility. Several biological factors i.e., organic matter, microorganisms, biogeochemical cycles, and soil mineralogy contribute to soil fertility. These factors result in the replenishment of old nutrients with new ones.

7.1 Organic matter [7]

Organic matter is formed by the dead bodies of animals and plants, fungi, insects, etc. Humus, leaf litter, and animal manures constitute organic matter. The soil contains approximately 5%of organic matter, so a major portion of soil fertility owes to it.

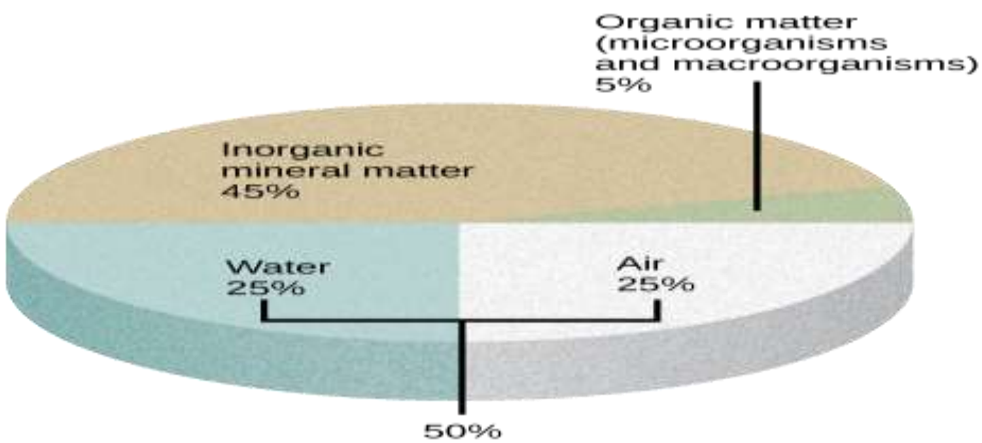

Figure 1: The globe showing the presence of different materials in soil such as organic matter which is the mostly the dead remains of animals and plants is 5% by volume, water constitutes almost 25% of the total volume, air is almost the same amount but the highest amount is that of inorganic mineral matter in form of rocks and earthly material i.e., 45%.

The organic matter is responsible for the smoothness of the surface of soil i.e., the soil texture and its surface. As the different materials degrade, the release of several important elements such as nitrogen, phosphorous, iron, etc. takes place hence increasing the fertility content. Farmers intentionally increase the amount of humus in their fields to increase soil quality.

7.2 Microorganisms [8]

Soil harbors a wide variety of microbes including bacteria, actinomyces, fungi, protozoa, etc. Bacteria are present in the greatest amounts. They contribute to major mineral recycling such as Nitrogen, Phosphorous, and Carbon, etc. Nitrogen fixers are present in soil which usually enhance the available nitrogen to plants and hence fertility. This abundance decreases to actinomyces, molds, algae, and so on. Some microorganisms are present within the soil which helps in the inhibition of other pathogens' growth. Fungi as mycorrhiza, which is the association between plants and fungi in which both partners get benefits also, improve soil fertility. Moreover, fungal association with algae known as lichen serves as bioindicator as well as soil quality index.

Organisms	Live weight per acre 6⅔"	Relative numbers
	Pounds	*Percent*
Bacteria	1,000	60-90
Actinomycetes	1,000	10-40
Molds	2,000	1-10
Algae	100	1
Protozoa	200	2
TOTAL	4,300	
DRY WEIGHT	1,000	
Nematodes	50	
Insects	100	
Worms	1,000	
Roots (dry weight)	2,000	

Figure 2: The occurrence of different microbes in soil environment being bacteria in abundance i.e., 60-90% narrowing to lesser percentage, 10-40% of actinomycetes, molds are in the ratio of 1-10% then trace numbers of algae and protozoa. Nematodes, insects, worms and dry weight of roots approximately constitute 3,150 live weights per acre of the soil. The characteristic of a fertile soil is the presence of more bacteria as compared to a non-fertile soil.

7.3 Biogeochemical cycles [9]

Nutrients such as N, P, C, etc. can't be taken up by plants as it is but they have to be converted into their standard forms with help of microbes and nutrient cycling. The repeated cycles in nature occur rapidly and are hence called biogeochemical cycles. Some of the major nutrient cycles are: -

- **Carbon cycle:** Photosynthetic plants and photoautotrophic microbes are involved. The carbon cycle refers to the transfer of carbon to different spheres i.e., hydrosphere, biosphere, lithosphere, etc. Certain *hydrogenotrophic* and *methanogenic* bacteria are involved in the carbon cycle. The steps of the carbon cycle include photosynthesis, respiration and combustion.

- **Nitrogen cycle:** Nitrogen is an important nutrient as it is essential for nucleic acid components, protein synthesis, and chlorophyll formation in plants. Nitrogen is the major constituent of the environment. The four steps include: - The first one is nitrogen fixation which is the conversion of atmospheric nitrogen into NH3, the major constituent of proteins. *Rhizobium* and *Anabaena* are majorly involved in this step. Next is nitrification which is the conversion of NH3 to nitrates and nitrites. *Nitrosomonas* and *Nitrobacter* are main examples. Then comes the assimilation step which is the utilization of the converted products by plants, the main reason for soil fertility. The last step is denitrification, the step which involves the converting back of molecular nitrogen to nitrites or nitrates.
- **Sulphur cycle:** The movement of Sulphur in nature is termed the sulfur cycle and is an important step in maintaining soil fertility. Soil organic Sulphur contributes to fertility with help of *rhizosphere* microbes. Chemoautotrophic bacteria such as *Thiobacillus*, *Chlorobium*, *Chromatium* are very important in this aspect. Bacillus, Pseudomonas, Aspergillus help in the conversion of sulphates in inorganic acids by different steps. In addition to this, *Desulfovibrio* helps in the reduction of Sulphur in soils.
- **Phosphorous cycle:** The recycling of phosphorous in the environment is the phosphorous cycle. *Bacillus* and *Pseudomonas* help in returning phosphorous to the environment. Fungi and *actinomyces* which are *Aspergillus*, *Penicillium*, and *Streptomyces* specifically help in soil fertility by phosphorous availability.

7.4 Soil mineralogy

It refers to the presence of minerals present in soil. Soil is a rich source of nitrogen, phosphorous, sulfur which helps in increased soil fertility and quality. The areas with high volcanic eruption have high fertility. The clayey mineral soils have high organic matter content so the fertility increases. Oxides of different elements also increase soil fertility.

8. Importance of Soil Fertility [10-15]

According to National Soil Survey Center, soil is defined as dynamic and living source that contains organic matter, microorganisms and different size of mineral particles and also contain physical, biological and chemical properties that can be changed. Nutrient enriched soil is termed as “fertile”. Agricultural products sustainability is based on “feed soil to feed plant”. This philosophy is designed to enhance the soil fertility by giving organic matter to the soil, nutrient, fertilizers and biological activity. As organic matter such as green manure, compost and crop residues are used to enhance the organic matter of soil which ultimately improves the nutrients that increase the crop production.

Soil feeds the plants which ultimately feeds animals and humans. Effective management of soil nutrients is essential as it feeds 7.3 billion people. It forms the basis of human existence and contains organic and inorganic compounds, decomposing organic matter and nutrients. When soil components break down, it will provide essential elements to plants and animals as essential nutrients. Fertilization will supplement the soil with additional nutrients and improves soil quality, yield and profits [10-12].

Basically, three ways are utilized to replenish soil nutrients:

1. By animal waste
2. Fertilizers
3. Microbial action such as nitrogen fixation

8.1 How fertilizers improve soil fertility?

In past few decades, intensive farming that includes pesticides, insecticides and fertilizers are having bad impacts on structural and microbial environment of soil. Chemical fertilizers that are not used by plants remain there in unavailable form. When there is rainfall soon after the application of chemical fertilizers to soil, they get washed away and accumulate in water bodies causing algal blooms and water pollution [15].

To reduce the adverse effects of chemical fertilizers, organic fertilizers are used. Organic fertilizers improve soil quality and improves their physical and chemical properties. Organic manures include compost, bio fertilizers, farmyard manures and green manures. Organic fertilizers improve physical properties by increasing porosity and aeration, declining sodality; reduce bulk density, water infiltration and improving soil leaching. Humus content improves biological content that help to intake macro nutrients and micro nutrients.

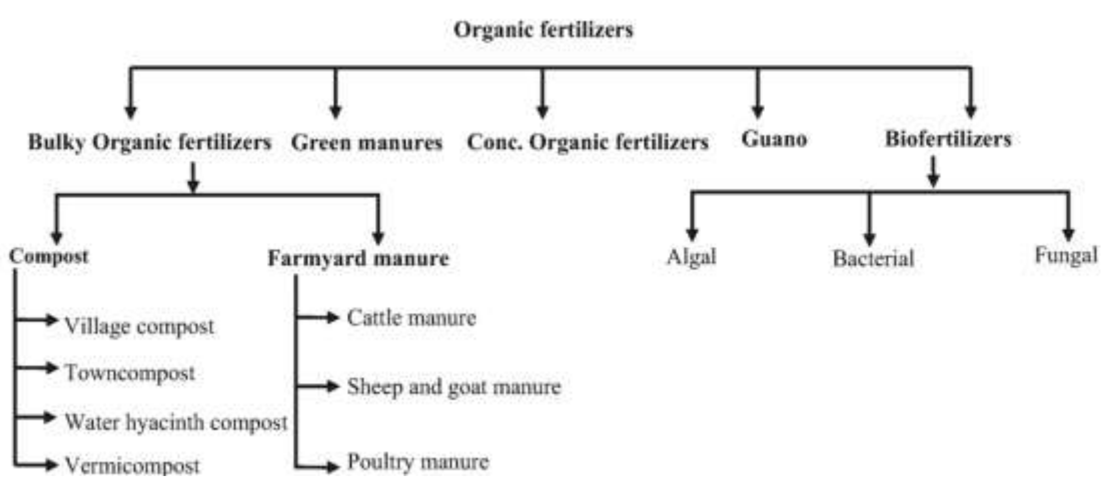

Figure 3: The schematic diagram of classification of organic fertilizers which help improve the soil fertility. The most abundant and significant are the bulky organic fertilizers which are further divided into compost and its types, the farmyard manures (manure from different animals). The green manures, conc. Organic fertilizers and guano are also used but the most environments friendly and pollution-free are the bio fertilizers which employ microbes for enhancing fertility without any waste products.

8.2 How manures improve soil fertility?

Animal manure benefits the soil chemical properties and fulfils the desirable number of nutritional requirements. Basically, manure composition is based on its chemical properties. Acidity has negative impact on soil and manure acidity must be monitored to avoid problems. Beef manure that is rich in carbon source maximizes soil nutritional content for crops. Reduction in bulk density of soil is due to long term use of manure that increases soil porosity and soil compaction diminishes.

Composting and manure application significantly increase large macro aggregates that are water stable. Rising of stable aggregates provide better environment for plants as provide strength to roots, water infiltration and retention. These good effects lead to runoff, erosion and less problems of soil in wet time and provide strength in dry conditions to drought. They further make soil more resistant to compaction and soil erosion [16].

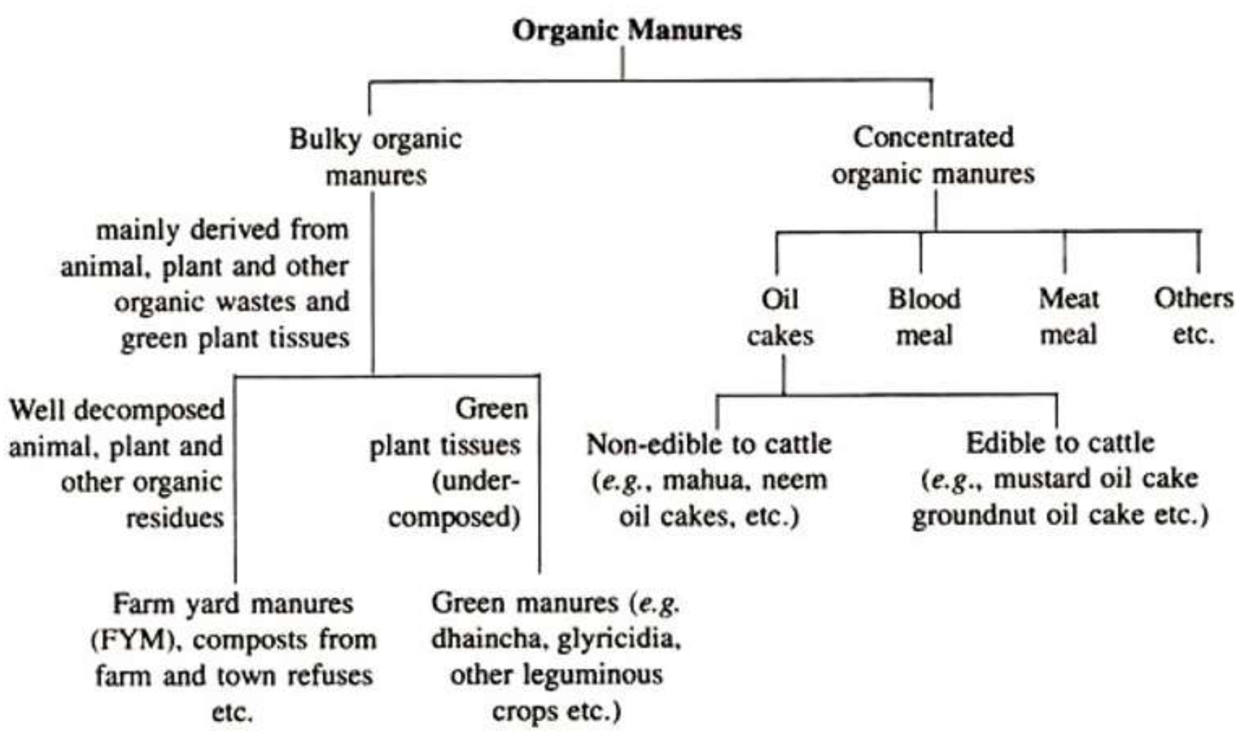

Figure 4: Manures are basically the dung produced by different animals meant for improving fertility of soil. Organic manures are the most favorable tool for this purpose because purely natural products are being used. This diagram is explaining classification i.e., bulky organic manures which are produced from both plant and animals waste and they are subdivided into farmyard and green manures (as they are produced mainly from plants). The important ones are the concentrated organic manures used and include oil cakes, blood meal etc.

8.3 Biodiversity of animals and soil fertility [17, 18]

8.3.1 Biodiversity refers to the diversity of living organisms on this planet, as well as other species that have perished millions of years ago; such as bacteria, plants, animals, and habitats such as coral reefs, woodlands, rainforests, and deserts. Animal biodiversity includes a diverse range of faunas, each with distinct physical characteristics, compositions, and functions. For example, rabbits and moles excavate holes and assist in the soil mixing. They allow water to seep through the soil and reach plant roots and give places for plant roots to grow hence increasing soil fertility.

8.3.2 Protozoa: Protozoa are microorganisms that can only be seen under a microscope. They contain many nutrients that crops can use when they eat bacteria, fungus, and other protozoa; enhancing soil fertility.

8.3.3 Fungi: Fungi are usually divided into two parts. Their thread-like structures can be found growing in dirt, decomposing wood, and roots. The threads of some fungi spread through the soil from the roots. Fungi aid plants in obtaining nutrients in the soil in this way. The beneath strands are linked to the mushrooms that grow above ground.

8.3.4 Bacteria: 50 million one-celled bacteria could be found in one teaspoon of topsoil! They assist in the dead and decaying plant and animal debris. They achieve this by releasing nutrients that can be used by other bacteria, tiny animals, and plants N - fixing bacteria can convert nitrogen gas from the air into a format which plants can use to grow. Some of these bacteria live in the roots of beans peas and other legumes.

8.3.5 Soil animals: Soil animals play a vital part in soil structure creation. Soil animals make the soil structure better by producing channels and pores, concentrating tiny soil particles into aggregates, and fragmenting and mixing organic substances throughout the soil.

Soil animals are engaged in various activities:

- The decomposition of organic materials and the mineralization of nutrients
- Pathogen populations under control
- Soil structure improvement and maintenance
- Incorporating organic materials into the soil

8.4 Biodiversity of plants and soil fertility [19]

There is some relation between biodiversity of plants and soil fertility and it is observed that this relation is positive. This relation also varies according to habitats, and biotic and abiotic factors also have some effect on it. About 163 studies were done in order to observe this relation. Variety of plants affect soil fertility by increasing the availability of different nutrients in soil, like plants that have relationships with nitrogen fixers makes nitrogen available in soil. Association between different ions in soil and biodiversity was also observed. The availability of N,Mg,P was more in areas with trees than those that don’t have trees. Biodiversity of plants also has effect on nutrient cycles like nitrogen cycle, phosphorus cycle. Experiments were done in order to observe the effect on nutrient cycles. Like for studying the effects on nitrogen cycle small experimental plots were created in which different number of different plants were grown under similar conditions in same field. Undesirable plants were removed during regular checking. The results obtained from experimental plots were compared because only a number of plants grown were different.

Plots that have greater number of plants can form more associations with nitrogen fixing microorganisms and hence can fix greater amount of nitrogen making it available to soil. Also these plants prevent leaching of nitrogen which prevents nitrogen wastage and eutrophication of water bodies.

Another aspect to consider here is that the greater the plant biodiversity, greater will be the decomposition of organic matter in soil. When large number of plants undergoes decomposition, there will be more nitrogen available in soil and hence there will be increase in soil fertility. Another major nutrient is phosphorus and plant biodiversity also have a positive effect on soil phosphorus. Same goes for other nutrients as well.

9. Conclusion

Fertility of soil is crucial as it forms the basis of human existence. Soil feeds the plants which ultimately feeds animals and humans. A positive relationship is observed between biodiversity of plants and animals and fertility of soil. Large biodiversity leads to greater accumulation soil organic content that enhances the soil productivity than small diversity ecosystem. Effective soil management is implemented to ensure high productivity for economic viability and maintenance of soil fertility.

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