

Chapter

Soil Fertility Management in Sugarcane

Denis Magnus Ken Amara, Melvin Sidikie George, Osman Sidie Vonu, Sheriff Bangura, Emmanuel Alpha, Foday Saidu Sesay, Alpha Sheku, Abu Bakarr Conteh, Samuel Josie Domingo, Michael Jusu and Foday Turay

Abstract

Sugarcane commonly known as “*Saccharum officinarum L*” is a major cash crop that holds significant importance in global sugar production. It contains roughly 84% pure juice and 16% dietary fiber and offers both sweetness and digestive benefits, promoting regular bowel movements. Sugarcane is a nutrient-intensive crop, and its continuous cultivation depletes soil nutrients. This makes it essential for nutrient restoration through proper soil management practices. Effective soil fertility management is therefore pivotal in achieving optimal yield, quality, and sustainability in sugarcane crop production. This ensures that sugarcane plants access essential nutrients throughout their growth cycle for maximum yield. Nutrients such as nitrogen, phosphorus, potassium, and various micronutrients are necessary for plant metabolism, photosynthesis, root development, and sugar accumulation. Adequate nutrient availability also contributes to better tillering, higher number of millable canes (NMC), and increased biomass production, all of which positively impact cane productivity. Deficiency of essential nutrients can hinder the growth and development of sugarcane, as well as impact various physiological processes. Hence, balancing nutrient availability and maintaining soil fertility is crucial for sustainable sugarcane production. Healthy soil enhances plant vigor and overall health and makes the crop more resistant to diseases and pests. Therefore, regular soil testing is a valuable tool for identifying nutrient status, deficiencies, and developing appropriate nutrient management strategies. Soil testing and analysis can help in determining the specific nutrient needs of the soil, allowing for more targeted and efficient fertilization. This chapter therefore discusses the key issues pertaining to the management of soil health and fertility for sustainable sugarcane production.

Keywords: soil pH, soil fertility, essential nutrients, nutrient deficiencies, soil management practices

1. Introduction

Agricultural production systems have been developed to meet the food, fiber, and feed needs of the growing population at the cost of natural ecosystem. Agricultural land management in the past has stressed the soil system, and continuous cultivation and intensive cropping have resulted in loss of soil through erosion and decrease in soil organic matter. The widening NPK ratio is also detrimental to soil health.

Soil degradation due to negative environmental conditions resulting in deterioration of soil health is a matter of serious concern and needs urgent attention. The integrated adoption of proper crops and cropping systems, use of soil amendment, green manuring, and provision of adequate agronomic practices is necessary for soil health and fertility management in sugarcane-growing soils.

The definition of soil health commonly used by agriculturist has emphasized soil productivity, that is, a healthy soil produces abundant, high-quality crops. But recently, thinking about agriculture has shifted as part of a much broader ecological system, which interact with and affect other part of the system. The new definition of soil health goes beyond productivity and connects with the environment as a whole. Now, we define soil health for agriculture as the “soil’s fitness to support crop growth without resulting in soil degradation or harming the environment.”

Sugarcane crop is an important cash crop globally, contributing to about 70% of the world’s sugar supply [1]. It is a tropical plant that requires warm and humid climate for good growth [2]. It accounts for about 84% of pure juice and 16% of dietary fiber. It offers both sweetness and digestive benefits and thus promotes regular bowel movements. However, its productivity is still low due to several factors, and many of them are soil-related. Looking at the current variability in yield, there is a wide scope for increasing the productivity of sugarcane by maintaining soil health and fertility, which are key to improving growth conditions and doubling yield at farm level. This will help to sustain sugarcane production and minimize negative environmental impacts.

2. Nature of problems faced in the management of soils under sugarcane cultivation

Soil quality is a composite picture of the state of the soil, that is, physical, chemical, and biological properties and of the processes that interact to determine this quality. Doran and Parking [3] suggested certain indicators to assess soil quality (**Table 1**), but this being of indicative nature need further intensive refinement for quantitative characterization with respect to easily determinable and more important distinguishing parameters.

Soil health and fertility go hand in hand. Their maintenance at the optimum level usually does not receive full attention in almost all parts of yield improvement programs. Poor soil and water management is one of the limiting factors for achieving higher crop yields with optimum input in sugarcane. A good soil fertility management program should provide the crop with adequate supply of air, water, and macro- and micronutrients, as well as protect the soil from marginal conditions such as acidity, salinity, alkalinity, water logging, flooding, compaction, and infestation of weeds and pests.

Soils under sugarcane cultivation pose a variety of problems in their management based on their differences in physico-chemical characteristics, climate conditions, and adequate supply of water during active period of crop growth. The main problem generally faced by farmers in sugarcane cultivation can be broadly summarized as follows (**Table 2**) [1, 4–6].

Physical properties	Chemical properties	Biological properties
• Soil aggregate stability and size distribution • Soil compaction • Bulk density • Total porosity • Air-filled porosity • Soil strength • Penetration resistant • Available water capacity • Soil depth • Hydraulic conductivity • Infiltration rate • Drainage and erosion, etc.	• Total organic C • Total nitrogen (N) • Nitrate-N • Ammonium-N • Available phosphorus (P) and potassium (K) • Available micronutrients • Ph • Electrical conductivity (EC) • Cation exchange capacity (CEC) • CaCO₃ • Exchangeable cations and anions • Nutrients toxicities • Sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP), lime or gypsum requirement	• Microbial biomass carbon (C) and N • Soil respiratory rate • Soil enzyme activity • Fungi hyphae growth • Ergosterol concentration • Arbuscular mycorrhiza • Earth worm population • Total and predacious number of nematodes and ants. • Microbiological status (total beneficial, hazardous)

Table 1.
Important physical, chemical, and biological indicators of soil quality for sustainable sugarcane production.

No.	General constraints	Associated problems	Effects on sugarcane crop
1.	Highly compacted soil	No aeration, restricted root growth imbalance in air and water relationship	As bulk density increases, the yield of cane decreases.
2.	Soils highly acidic, calcareous, saline or alkaline in reaction	Inadequate supply of nutrients to the soil	Causes nutrient deficiencies, impedes root development, disrupts organic matter decomposition and nutrient cycling, leads to osmotic stress, damages plant tissues and impairs metabolic functions.
3.	Soils low in fertility and improper method of fertilizer application	Low in organic matter, rate of availability of nutrients in the soil is very low	Reduced growth rates, stunted growth, and reduced biomass due to poor nutrient availability. Low stalk height and weight, ultimately resulting in decreased yield. Hinder plant ability to synthesize and store sugar, leading to lower brix (sugar content) levels and reduced sugar quality. Nutrient imbalances and disruption of nutrient uptake. Less resistance to environmental stresses such as drought, extreme temperatures, and salinity. Slow development and delayed maturation of sugarcane, which affects harvesting and overall profitability of the crop.
4.	Very shallow soils or very deep soils	Soil surface runoff or excess drainage due to high fixation of P and K	Limited root development; nutrient deficiency; water stress; increased competition with weeds and other plants for nutrients, water, and space; limited soil aeration; potential for soil erosion if not managed properly.
5.	No or low response to P and K fertilization in soil	Imbalance in the use of P and K	Nutrient deficiencies; reduced yield; poor plant health; low sugar storage; long-term fertility issues; farmers may face reduced profits due to low production efficiency, increased competition with weeds and other plants for nutrients, water, and space.

No.	General constraints	Associated problems	Effects on sugarcane crop
6.	Losses of nutrient through leaching, volatilization, and denitrification	Deficiency of essential nutrients	Significant nutrient losses in the soil adversely affects the growth, yield, and sugar contents of the plants. Deterioration of soil structure, thus water-holding capacity, and affecting root development.
7.	Injudicious use of irrigation water	Adverse effect on soil temperature, air, water balance, and microbial activity	Water logging, accumulation of salts, reduction in water uptake and nutrient absorption, stunted growth, low sugar content, nutrient leaching, creation of humic environment that is conducive to the proliferation of pests and diseases, reduced crop yield and quality, soil compaction, reduced aeration, hampering of root growth and water infiltration.
8.	Lodging of cane due to excess use of N and inadequate K	Reduction in cane yield	Reduced yield, decreased quality, harvesting challenges, increased pests and disease incidence, altered growth dynamics, soil erosion, and nutrient losses.
9.	Inadequate use of bulky manure	Deterioration in soil fertility and soil structure	Nutrient deficiencies leading to stunted growth, reduced sugar content, and low yield. Compacted soil with reduced porosity and poor drainage. Poor root development and decrease in soil's ability to retain moisture. Decreased microbial activities. Crop becomes more susceptible to pests and diseases, potentially leading to crop losses.
10.	Imbalance in the use of NPK fertilizer	Tendency to apply only N	Nutrient deficiencies and toxicities, yield reduction, soil acidification nutrient leaching, reduced microbial activity, and soil pollution.
11.	Inadequate weed control	Crop growth adversely affected	Competition for resources, stunted growth, reduced photosynthesis, reduced energy for sugar accumulation, pest and disease reservoir, harvesting challenges, economic losses through yield losses delayed crop maturity.
12.	Inadequate pests and disease control	Crop adversely affected	Reduced yields, crop quality deterioration, increased vulnerability, economic losses, increased farming costs, risks of crop failure, and resistance development.
13.	Ill-drained soils with high water table	Restricted root growth	Water logging, poor root development, nutrient leaching, favorable environment for pests and pathogens, stunted growth and poor root health, low sugar content, harvesting challenges, soil compaction, and degradation of soil structure.
14.	Deficiency of micronutrients such as Fe, Zn, Cu, Mo, and B	Poor growth and yield	Reduce leaf size, smaller internodes, impaired shoot growth and reduced cane yield, stunted growth, chlorosis, decreased photosynthesis, and reduced biomass production, leading to low sugar yield.
15.	Use of saline water for irrigation	Alkaline soils and poor yield	Inhibits seed germination and early growth stages, osmotic stresses, reduced turgor pressure, stunted growth and plant wilting, nutrient imbalances, reduced chlorophyll content and photosynthesis, altered plant water relations leading to increased transpiration rates, yield reduction, altered root structures and root dieback, deterioration of soil structure, soil salinization, and reduced fertility.
16.	Delay in tillage and inter cultivation operations	Damage to soil structure and microorganisms	Soil compaction, increased weed growth and competition with sugarcane crop, and increased pests and disease incidence, hinder timely planting and establishment of sugarcane leading to reduced growth and yield.

No.	General constraints	Associated problems	Effects on sugarcane crop
17.	No suitable crop rotation and no scientific planning	No record of specific operation or observation	Soil may become less fertile, which may negatively affect the growth and yield of sugarcane crop. Poor soil structure over time. Reduces biodiversity in cropping systems, which can negatively affect soil microbial communities. A wide range of agronomic and environmental challenges. Promotes growth of weed species that thrive in sugarcane fields leading to increased competition for resources.

Table 2.
Problems faced by farmers in the management of soils under sugarcane cultivation.

3. Ideal soil requirement for healthy sugarcane crop

Sugarcane grows well in a wide variety of soil types ranging from sandy loam to heavy clay [7], with pH varying from 5.5–8.5. It makes good demand for oxygen supply. It can tolerate deep soils, but it is very susceptible to compaction. Thus, sugarcane crop requires a well prepared, well-structured, and well-aerated soil to a depth of about 60 cm with no compaction or hard pan in the subsoil. Depending on the variety and texture of the soil, the cane is moderately tolerant to salinity. The optimum density for good growth is 14 gm/cm³. The roots and shoots of the crop are adversely affected by high bulk density. Even the uptake of P by the crop is affected by high bulk density.

Sugarcane is a high-nutrient demanding crop. A crop having an yield of 100 t/ha removes 207 kg N, 30 kg P₂O₅, and 233 kg K₂O from the soil [8]. For production of 150 mt/ha cane yield, the crop removes a total of 315 kg/ha N, 386.4 kg/ha P₂O₅, and 519.2 kg/ha of K₂O from the soil. Total uptake of N, P₂O₅, and K₂O is 1220.6 kg/ha. Therefore, these elements must be added in adequate quantities in the root zone of the crop to obtain higher yield.

The recommended dose of fertilizer is 400:170:170 kg/ha nitrogen, phosphorus, and potassium (NPK) for adsali, 340:170:170 kg/ha NPK for preseasonal and 250:115:115 kg/ha NPK for saturation for all varieties except Co–86,032. For Co–86,032, the recommended dose of fertilizer is 500:200:200 kg/ha NPK for adsali, 400:170:170 kg/ha for preseasonal and 300:140:140 kg/ha for saturation. The time of doses of fertilizer application are 10:50:50% NPK at the time of planting, 40% of N at the time of 6–8 weeks after planting, 10% N at 12–16 weeks after planting, and 40:50:50% NPK at the time of final earthing up. The recommended dose of fertilizer can be used in balanced proportion by using six-tiered nutrient classification basis or yield-targeted fertilizer prescription equations so as to maintain soil health and fertility as well as achieving yield target also. Application of the recommended dose of fertilizer in two equal splits either at planting and within 30 days after planting (DAP) or at 30 and 60 DAP benefited the crop so that more millable canes were produced at harvest which ultimately resulted in increased cane and sugar yield [9].

It has been observed that the incorporation of chopped trash @10 T/ha + urea @ 8 kg/ha of trash and mix culture @ 1 kg/ha of trash showed good effect in increasing the cane yield of 134.5 MT/ha than addition of decomposed trash or FYM under adsali condition (**Table 3**).

Increase in bulk density of soil can adversely affect the percentage distribution of roots even at 4 months of the crop age (**Table 4**).

Treatment	FYM@5MT/ ha	Decomposed trash @ 5 MT/ha	Control (no organic matter)	Chopped trash + urea + culture	CD
Cane yield in MT/ha	109.64	131.3	93.1	133.2	5.34

Table 3.
Cane yield under different nutrient management.

Treatment	Bulk density (g/cm ³)	Root distribution at different depths in a 4-month-old sugarcane			
		0–15 cm	15–30 cm	30–40 cm	45–60 cm
Normal	1.2	49.0	31.4	12.4	7.1
	1.4	54.0	37.0	10.6	4.4
	1.6	57.8	27.0	9.4	3.8
FYM	1.2	45.5	32.5	19.1	3.1
	1.4	54.2	28.5	14.1	3.0
	1.6	59.7	23.5	14.1	2.3

Table 4.
Effect of bulk density on percentage distribution of sugarcane roots.

Soil amendments with poultry manure at equivalent nitrogen dose shows higher yield than FYM + urea and FYM (**Table 5**). Crop receiving 150 kg/ha N shows the highest yield of 119 t/ha by 24 t/ha more than the control (**Tables 6 and 7**).

Soil samples analyzed at grand growth period of cane exhibited on an average, high organic carbon, available P and K in the P + K over P-enriched PMC or K-enriched PMC alone (**Table 8**). Similarly, as expected, full RD of P and K enrichment also exhibited higher organic carbon, available P and K in soil. At harvest, similar trend was observed but with lower magnitude, and P + K-enriched PMC proved to be better in improving soil nutrient status.

Sr. no.	Source of fertilizer	Cane yield (t/ha)				
		Nitrogen (kg/ha)				
		Control	50.0	100.0	150.0	Mean
1	Control	95.0	—	—	—	95.0
2	Urea	—	100.0	107.0	115.5	107.5
3	FYM	—	104.0	105.0	115.0	108.3
4	Neem cake-coated urea	—	102.0	105.0	116.0	107.0
5	Poultry manure	—	109.0	114.5	129.0	117.0
6	FYM + urea	—	107.5	112.3	121.5	113.0
	Mean	95.0	104.5	109.0	119.0	—

Table 5.
Cane yield (2-year mean) under different nitrogen sources.

Treatment no.	Crop (t/ha)		Cane yield (t/ha)		CCS (t/ha)	
	Grain	Fodder	Plant	Ratoon	Plant	Ratoon
T ₁ – Soybean-PS – Ratoon (NPK-RDF and micronutrient to all crops)	30.0	56.0	156.0	83.0	22.8	12.1
T ₂ – Soybean-PS – Ratoon (FYM @ 20 t/ha – sugarcane, NPK-RDF, and micronutrients)	31.0	61.5	165.0	103.0	24.4	15.2
T ₃ – Soybean-PS – Ratoon (FYM @ 20 t/ha to soybean, 50% RD – N, 100% RDF – P and K to all crops)	29.0	50.0	150.0	80.0	22.4	11.9
T ₄ – Dhaincha-PS – Ratoon (NPK-RDF with Micronutrients)	—	358.0	169.0	102.0	25.2	15.1
T ₅ – Soybean-PS – Ratoon trash compost 10 t/ha + PMC + 10 t/ha to sugarcane, NPK-RDF with micronutrients)	32.0	65.0	159.0	101.0	23.8	15.0
T ₆ – Dhaincha-PS – Ratoon (50% RDF – N and 100% RDF – P and K)	—	269.0	147.0	78.0	21.5	11.4
T ₇ – Soybean-PS – Ratoon trash compost 10 t/ha + PMC + 10 t/ha to sugarcane, 50% RDF – N and 100% RDF – P and K)	25.5	41.5	147.0	78.0	21.5	11.2
T ₈ – Soybean-PS – Ratoon (50% RDF – N and 100% RDF – P and K)	24.0	40.5	136.0	74.0	19.2	10.6
SE	—	—	6.6	3.0	0.6	0.4
CD @ 5%	—	—	19.9	8.0	1.5	1.1

Note: PS = preseasonal sugarcane; RDF = recommended dose of fertilizer; PMC = pressmud cake, CCS = commercial cane sugar.

Table 6.
Yield of different cropping systems on the yield of Kharif crop and yield parameters of sugarcane (mean of two cycles).

Treatment no.	Organic carbon			Available N (kg/ha) (Initial 171.0)		
	Kharif	Pl. cane	Ratoon	Kharif	Pl. cane	Ratoon
T ₁ – Soybean-PS – Ratoon (NPK-RDF and micronutrient to all crops)	0.57	0.59	0.60	199.0	190.0	203.0
T ₂ – Soybean-PS – Ratoon (FYM @ 20 t/ha – Sugarcane, NPK-RDF and micronutrient)	0.56	0.62	0.64	197.0	195.0	209.0
T ₃ – Soybean -PS – Ratoon (FYM @ 20 t/ha to soybean, 50% RDF – N, 100% RDF – P and K to all crops)	0.56	0.58	0.62	202.0	175.0	188.0
T ₄ – Dhaincha - PS – Ratoon (NPK-RDF with micronutrient)	0.62	0.64	0.67	213.0	199.0	214.0
T ₅ – Soybean - PS - Ratoon trash compost 10 t/ha + PMC + 10 t/ha to sugarcane, NPK-RDF with micronutrient)	0.58	0.65	0.65	197.0	187.0	214.0

Treatment no.	Organic carbon			Available N (kg/ha) (Initial 171.0)		
	Kharif	Pl. cane	Ratoon	Kharif	Pl. cane	Ratoon
T ₆ – Dhaincha - PS – Ratoon (50% RDF – N and 100% RDF – P and K)	0.62	0.61	0.65	223.0	182.0	196.0
T ₇ – Soybean-PS – Ratoon trash compost 10 t/ha + PMC + 10 t/ha to sugarcane, 50% RDF – N and 100% RDF – P and K)	0.55	0.56	0.64	194.0	173.0	192.0
T ₈ – Soybean-PS – Ratoon (50% RDF – N and 100% RDF – P and K)	0.56	0.55	0.63	192.0	167.0	189.0

Table 7.

Yield of different cropping systems on the yield of organic carbon and available N content in soils of sugarcane cropping systems.

Treatment	Yield (MT/ ha)	CCS (MT/ ha)	Soil organic carbon (g/kg)		Soil available P (kg/ha)		Soil available K (kg/ha)	
			Grand growth	Harvest	Grand growth	Harvest	Grand growth	Harvest
Nutrient RD								
T1 = P-80 kg/ha	66.23	7.60	5.8	5.2	19.93	18.53	150.5	139.1
T2 = K-60 kg/ha	66.79	7.73	5.7	5.3	19.99	18.17	156.6	146.9
T3 = P + K, 80 + 60 kg/ha	69.58	8.08	6.0	5.4	20.42	18.77	158.5	145.5
Level of nutrients								
T4 = 50% RDF	65.52	7.57	5.7	5.2	19.47	18.28	152.9	141.1
T5 = 100% RDF	69.32	8.08	5.9	5.3	20.48	18.62	157.5	146.6
Microorganisms								
T6 = 0 PSB	66.20	7.65	5.8	5.2	19.34	18.13	154.3	142.5
T7 = 6 kg PSB	68.66	7.95	5.8	5.4	29.28	18.89	156.1	145.2

Table 8.

Effect of P, K, and biofertilizer-enriched PMC on yield quality and soil nutrient status under sugarcane cultivation at grand growth and harvest.

4. Nutrient requirements in sugarcane crop

4.1 Essential nutrients and their roles

Three major nutrients viz., N, P, and K; three secondary elements, viz., S, Ca, and Mg; and six micronutrients, viz., Fe, Mn, Cu, Zn, B, and Mo, are considered to be indispensable for the healthy growth of sugarcane crop. Among these elements, N is the primary nutrient limiting sugarcane production throughout the world [10]. World recommended rates of N fertilizer for sugarcane production vary between 45 and 300 kg/ha/yr. [11]. In some instances, the limitation to growth is caused not by the deficiency of the particular elements in the soil but by an excess of one or the

other element. In many cases, symptoms of certain nutrient deficiencies are not due to complete lack of such micronutrient in the soil or even to failure of the root system to take them up but rather due to immobility of the element within the plant, resulting in failure to maintain an adequate supply of the element in the metabolic centers where it is required. Under-feeding and starvation of the plant are the main causes for low yields of sugarcane in many parts of the world. It is therefore very essential that the deficiency of a micronutrient or a secondary element is detected at the very outset when the crop slows down in growth and exhibits signs of hidden hunger.

4.1.1 Role of iron (Fe)

1. It is very essential for normal growth of a sugarcane crop.
2. It has a direct connection with the formation and functioning of the chlorophyll.
3. It acts as a catalyst of redox enzyme in inorganic form or combined with organic compounds.
4. Respiratory energy required for salt accumulation is mediated by iron.
5. A healthy sugarcane crop possesses in leaf blade about 100–600 ppm of iron and deficiency appears when the level falls below 20 ppm.
6. Sugarcane crop absorbs iron through roots in the form of ferrous ion (Fe^{2+}).
7. It plays an essential role in building up protein (chlorophyll) and informing various carbohydrates.
8. The absorption of iron depends not only on the amount available in the soil but also on the presence of other heavy metals, such as zinc and especially manganese. If these are present in the soil to a great quantity, they may have an antagonistic effect.

4.1.2 Roles of manganese (Mn)

1. It plays an important role in the development of chlorophyll in leaves without entering into its molecular structure.
2. It takes part in catalytic reactions and enzymatic activities and regulates functions connected with nitrogen (protein metabolism) photosynthesis, carbohydrates metabolism, and intake of other elements.
3. In association with zinc and copper, it directs the nutrient elements that enter the plant cell to their respective positions.
4. Along with Fe, it acts as a chief oxidation-reduction regulator in plants.
5. A healthy sugarcane crop has in its leaf blade, about 190–400 ppm of Mn.
6. The deficiency of Mn is exhibited when the level of Mn declines below 200 ppm.

7. It is of more frequent occurrence in sugarcane than most of the other micronutrients.
8. It is a relatively immobile element in plant.
9. Under practical conditions, the soil pH, ventilation, organic matter content, and water retention capacity of the soil determines the crop's Mn supply.
10. Uptake is encouraged by low pH and severely inhibited by liming of acid soil. The more acidic the soil, the more soluble is the Mn.
11. Molybdenum (Mo) is said to be an even distribution of Mn in the plant.
12. The supply of Mn in the soil correlates with the CO₂ assimilation of the plants.
13. Mn is necessary for water splitting during photosynthesis (Hill reaction).

4.1.3 Roles of zinc (Zn)

1. Required in very minute amounts.
2. It is also associated with chlorophyll formation.
3. Availability at critical pH of soil is 6.0–6.5.
4. In a healthy sugarcane crop, the level of Zn in expended leaf blade varies from 10 to 100 ppm.
5. In case of droopy tops, the application of Zn stimulates good growth.
6. The amount of Zn present in leaf sheath is 70–100 ppm on dry matter basis.
7. Zn is only slightly mobile in soil and plant but more mobile in young leaves than in old ones. Its mobility increases with the acidity of soil solution. In plants, the Zn content is higher in roots.
8. *It acts as a metal component in a series of enzymes and play a major part in protein metabolism (i.e., formation of tryptophan, glycine, etc.).*

4.1.4 Roles of copper (Cu)

1. It is found in the enzyme tyrosine, which plays an important role in respiration and other enzymes that act as a catalyst and regulator of oxidation-reduction reactions in plants and chlorophyll formation.
2. It is regarded to be important in protein metabolism.
3. A healthy sugarcane crop contains between 5 and 50 ppm Cu in its organs. Deficiency occurs when the Cu content drops below 3.5 ppm in the leaf blade.

4. As much as 70% of Cu in sugarcane plant is concentrated in the chlorophyll, and its improved role can be seen in assimilation.
5. Cu is not readily mobile either in the soil or in the plant. Chelates assist in uptake.

4.1.5 Roles of boron (B)

1. It is needed for cell division, salt absorption, proper hydration, and metabolism of N and carbohydrates.
2. It is needed for translocation of sugar in plants.
3. It regulates K/Ca ratio and keeps Ca in solution.
4. It is a constituent of cell membrane.
5. It ranges from 50 to 200 ppm in soils, but available B varies from 0.1–12.2 ppm. The level of water-soluble B in soils above 1.5 ppm is considered unsafe for all plants.
6. Increase in pH of 8.5 decreases the availability of B in plants. Drying of soils increases fixation of B in soils.
7. A healthy sugarcane crop contains 2–30 ppm of B in the leaf blade. Deficiency develops when the level falls below 1 ppm.
8. B deficiency retards the uptake of Ca and renders the plant sterile.
9. B deficiency causes more loss of yield and growth inhibition than any other micronutrient. The average B content in sugarcane plant is 10 ppm.

4.1.6 Roles of molybdenum (Mo)

1. Required in physiological reduction of nitrates in the plant metabolism.
2. In the absence of Mo, nitrates accumulate in plant tissues.
3. Healthy sugarcane crop contains 0.05–4 ppm. Mo deficiency level in leaf blade is less than 1 ppm.
4. Activate many metabolism reactions.
5. Important for reducing nitrate and later to amide form of N.

4.2 Nutrient availability in soils

Every nutrient is required in a specific form and amount (or range) in the soil to support the sustainable growth of crop. However, in many cases, symptoms of certain nutrient deficiencies are not due to complete lack of nutrients in the soil or even to failure

of the root system to take them up but rather due to the immobility of the element within the plant and but by an excess of one or the other element, resulting in failure to maintain an adequate supply of the element in the metabolic centers where it is required. The availability of micronutrients as affected by other macro- or micronutrients (i.e., antagonism) and their mobility in soils and plants are summarized in **Tables 9** and **10**.

4.3 Factors influencing nutrient availability

There is no single soil factor which can be said to singly affect plant growth and subsequent yield. The interaction between environmental and soil factors is more important in determining growth and final yield than any single property in isolation [4].

4.3.1 Soil pH

The micronutrient cations are most soluble and available under acid condition. In very acid soils, there is a relative abundance of the ions of iron, manganese, zinc, and copper. In fact, under these conditions, the concentration of one or more of these elements is often sufficiently high to be toxic to common plants. As the pH rises, their suitability to plant decreases because ionic forms of cations are changed to hydroxides or oxides, hence the desirability of maintaining an intermediate soil pH. Generally, zinc-fixation is found at high pH value.

4.3.2 Oxidation state and pH

Three of the trace element cations are found in soils in more than valent state. These are iron (Fe^{2+} and Fe^{3+}), manganese, and copper. The lower valence state is

Si. no.	Micronutrient	Availability reduced by
1	Zinc	High levels of P and Cu
2	Copper	High levels of Zn, N, and P
3	Iron	High levels of Ca, Mn, Zn, and P
4	manganese	High levels of K, P, Fe, Cu, and Zn
5	Boron	High levels of P and Ca
6	Molybdenum	High levels of Mn and NO_3

Table 9.

Availability of micronutrients as affected by other macro- or micronutrients (i.e., antagonism).

Mobility status	Examples in soil	Examples in plant
Highly mobile	NO_3^- and SO_4^{2-}	N, P, and K
Moderately mobile	BO_3^- , Cl^- , and Mn^+	Zn
Less mobile	NH_4^+ , K^+ , Ca^{2+} , Mg^{2+} , and Cu^{2+}	S, Fe, Mn, Cu, Mo, and Cl
Immobile	H_2PO_4^- and Zn^{2+}	Ca and B

Table 10.

Nutrient mobility in soils and plants.

encouraged by conditions of low oxygen supply and relatively higher moisture level. The oxidized state of iron, manganese, and copper, that is, hydroxides or hydrous oxides are insoluble. The micronutrient cations such as Mo^+ are somewhat more available under conditions of restricted drainage. Flooded soils generally show higher availability than well-aerated soils.

4.3.3 Inorganic reactions

The availability of iron and zinc may be reduced in the presence of excess phosphate. From a practical stand point, phosphate fertilizers should be used in only those quantities that are required for good plant growth.

4.3.4 Organic combinations

Each of the micronutrient cations may be held in organic combinations. These complexes may protect the micronutrients from certain harmful reactions, such as the precipitation of iron by phosphates. On soils high in organic matter, complex formation by copper is thought to be responsible for the deficiency of this element.

4.4 Nutrient deficiency symptoms

4.4.1 Deficiency symptoms of Fe

1. Interveinal chlorotic or white stripes running full length of young leaves. Older leaves remain dark green.
2. Iron deficiency can be caused by excessive CaCO_3 content in soils, which prevents iron uptake (lime-induced chlorosis).
3. Iron deficiency is found in the Fe:Mn ratio 1:1, and the ratio 15:1 is desired.
4. The toxic effects of iron can be eliminated or reduced by liming and by potash and silicate fertilizer.
5. The leaf chlorophyll content is directly linked with the degree of Fe deficiency. It has no immediate connection with the total Fe content, as antagonism can cause iron chlorosis in plant with a high iron content.
6. After discolouration of intercoastal zones, the lamina turns yellow so that the darker veins stand out. Necrosis or even complete leaf fall may occur. Later, shoot may also die off.
7. Three causes of iron deficiency include the following:
 - a. Resulting from inadequate supply, that is, genuine Fe deficiency
 - b. Due to lack of mobility of Fe in the tissue
 - c. Due to unfavorable ratio of Fe:Mn

8. Excess of Zn, Cu, and Co induces a deficiency of Fe in plant. Fe deficiency can be reduced with foliar spray of Fe chelates.

Soil application of FeSO_4 @ 20 kg/ha and foliar spray of FeSO_4 @ 2% both are recommended for controlling chlorosis in sugarcane (**Table 11**).

4.4.2 Deficiency symptoms of Mn

1. Deficiency symptoms are usually observed in calcareous, alkaline, and extremely sandy soils, or soils having high humus.
2. The early symptoms are facing of normal green color between vascular bundles and the development of yellowish green to white strips.
3. The stripes remain confined to middle and top portion of the leaf. In acute cases, chlorotic leaves or stripes become white and turn reddish brown due to the death of the tissue and splitting of leaves longitudinally.
4. Mn deficiency is known to be associated with the deficiency of Cu, Zn, and K.
5. Mn deficiency in the plant can be reduced by the application of 15–30 kg/ha of Mn in the form of MnSO_4 .

The combined application of FeSO_4 + MnSO_4 + urea helps in the improvement of cane (**Table 12**). The application of FeSO_4 does not show 100% improvement, but it produces maximum effect on cane recovery.

It has been observed that due to the application of MnSO_4 , the cane yield increases from 0.5–2.5% over no application on soils having low levels of Mn (**Table 13**). Several investigations on the fate of added MnSO_4 to soils deficient in Mn and its effect on cane yield and quality have revealed that the application of Mn to soils deficient in Mn either through soil @ 22–43 kg/ha or through foliar spray @ 1% MnSO_4 three times after earthing up not only gives better brix and more sucrose juice but also helps to absorb more N, P, and K.

Sr. no.	Treatment	Cane yield (Mg/ha)	Reducing sugar (%)	Non-reducing sugar (%)
1.	Control	51.39	0.66	13.07
2.	10 kg FeSO_4 ha ⁻¹	54.94	0.62	13.95
3.	20 kg FeSO_4 ha ⁻¹	61.04	0.53	15.19
4.	40 kg FeSO_4 ha ⁻¹	62.71	0.54	14.51
5.	0.5% FeSO_4 foliar spray	52.28	0.62	13.40
6.	0.5% FeSO_4 foliar spray	56.05	0.51	15.00
7.	0.5% FeSO_4 foliar spray	60.38	0.51	15.63
	C.D @ 5%	3.05	0.42	0.34

Table 11.
Yield of sugarcane as influenced by the application of FeSO_4 .

Treatment	Weight of canes (kg)	Sucrose % in juice	Purity coefficient	Available sugar on cane basis (%)
Healthy cane	6.57	17.47	89.0	12.12
Affected cane	1.71	10.20	70.6	6.21
Treated canes				
FeSO ₄	3.81	15.12	82.1	10.07
MnSO ₄	1.86	10.47	74.6	6.60
FeSO ₄ + MnSO ₄	3.87	15.0	80.6	9.89
Urea	1.91	11.86	74.9	7.50
FeSO ₄ + urea	3.88	15.09	79.9	9.91
MnSO ₄ + urea	1.87	11.98	74.7	7.56
FeSO ₄ + MnSO ₄ + urea	4.43	15.36	82.5	10.26

Table 12.
Effect of FeSO₄, MnSO₄ and urea on the recovery of sugarcane.

Sr. no.	Variety	Available soil Mn (mg/kg)	MnSO ₄ application (kg/ha)	Cane yield (mg/ha)	
				Control	Treated
1.	CO-419	14.0	10	120.0	120.0
2.	CO-419	4.0	20	120.0	123.0
3.	CO-419	2.5	30	128.0	130.0
4.	CO-740	10.0	10	235.0	235.0
5.	CO-740	3.0	20	172.5	175.0
6.	CO-740	2.0	30	165.5	170.0

Table 13.
Sugarcane yields as influenced by MnSO₄.

4.4.3 Deficiency symptoms of Zn

1. Leaves exhibit chlorosis characterized by the appearance of a broad band of bleached tissues on either side of the major leaf vein.
2. There is a loss of chlorophyll in the vascular bundles and sheath of the main veins. In acute cases, the newly formed tillers become completely chlorotic.
3. In young chlorotic leaves, there is a development of anthocyanin pigments.
4. Leaves are short and abnormally wide at the midpoint of the blade.
5. Zn deficiency causes disturbances in the formation of protein.
6. Deficiency is easily eliminated by fertilizing with ZnSO₄.

4.4.4 Deficiency symptoms of Cu

1. Very poor development of the stool.
2. Leaves show chlorotic appearances.
3. Spindle leaf fails to unroll, leaves show dropping effect, referred to as droopy tops.
4. The foliage shows rectangular blotches and have unusual width.
5. Young tillers exhibit general yellowing and slight stunting in growth, but leaves become wider and soft to touch.
6. Areas of dead tissues appear along the tips and edges of leaves. The stalks become elastic.
7. Leaves show mild to severe interveinal chlorosis with small dark green spots.
8. Cu deficiency arrests growth and shows necrosis in older leaves of sugarcane crop.
9. The deficiency can be eliminated with CuSO_4 @ 30–60 kg/ha.

4.4.5 Deficiency symptoms of B

1. In leaves, minute elongated watery spots develop parallel to the veins or vascular bundles.
2. Small longitudinal sunken areas or depressions are seen.
3. There is gall-like out-growth on the lower leaf surface.
4. Cracks or fractures form.
5. Leaf size gets reduced, and stalk size also reduced.
6. Younger leaves become narrow and stunted.
7. Old leaves become narrow and stunted.
8. Spindles become distorted and ultimately die.
9. The B level in top visible dew lap is 1–4 ppm, while in healthy canes, it varies from 2 to 9 ppm.
10. Application of borax @ 10 kg/ha is recommended on soils deficient in B, especially vertisols.

Sr. no.	Micronutrient	Critical level (mg/kg)
1.	Zinc	0.6
2.	Iron	4.5
3.	Manganese	2.0
4.	Copper	0.2
5.	Boron	0.5
6.	Molybdenum	0.05

Table 14.
Critical levels of micronutrients.

4.4.6 Deficiency symptoms of Mo

1. Symptoms appear on mature leaves, which show yellow streaks which increases with advance in age.
2. Reddish pigments may also appear in more mature leaf in the center of streaks.
3. Symptoms of Mo deficiency in sugarcane are rarely seen.

The critical levels of micronutrients are given in **Table 14**.

5. Organic manuring in sugarcane cultivation

Virgin soils, when brought under cultivation, give good yields for a couple of years, and then the yield starts to decline unless application of organic manure. Organic manure is regarded as the life blood of the soil because it keeps the soil in a good condition required for plant growth. The role of organic manures has been studied in great detail, and ways and means were found out to augment their supply. Of late, the use of chemical fertilizers has also increased considerably, but the importance of organic manures has not diminished, as they are necessary for both soil and plant, and without which fertilizers alone would not give best results. In these days of food shortage, manures and fertilizers have assumed a very high place in intensive farming because they alone increased food production by at least 50%.

5.1 Importance of organic manures in sugarcane nutrition

There are a variety of manures and fertilizers available in the market, but they can be classified into two broad groups: (1) natural or organic manures and (2) artificial or chemical fertilizers. The organic manures may be further classified into two groups: (1) bulky organic manure and (2) concentrated organic manures.

1. Organic manures when added to the soil increase organic matter content and improve the physical condition of the soil. Such manures bind sandy soils and improve its water holding capacity. They open clayey soils and help in aeration and better root growth.

2. They add plant nutrients in small percentage and increase the fertility of the soil. Besides NPK, they also add micronutrients, which are so very essential for plant growth.
3. The soil microbial activities are increased, which help in rapid decomposition of organic matter and release plant nutrients in available form.

5.2 Farm yard manure

Farm yard manure is a mixture of cattle dung, urine, litter or bedding materials, portion of fodder not consumed by cattle, and other domestic wastes like ashes etc., collected and dumped into a pit or a heap in the corner of the back yard. It is allowed to remain there and rot till it is taken out and applied to fields. Because of the varied nature of the material, the composition of the manure itself varies widely, but on average, well-rooted farm yard manure contains 0.5% N, 0.2% P_2O_5 , and 0.5% K_2O .

5.3 Compost

Well-rotted plant and animal residue is called compost. Composting means rotting of plant and animal remains before applying in the fields. The essential requirements of composting are air, moisture, optimum, temperature, and a small quantity of nitrogen. It is an activity of microorganisms, and some people recommend addition of suitable prepared inoculum to introduce microorganisms for decomposing the material. It is, however, not found necessary as the decomposing material and soil always carry the required organisms. There are two different types of composts: (1) farm or rural compost and (2) town or urban compost. The essential principle underlying their preparation is the same, but the composting material used and the decomposition of the final product differs.

5.4 Night soil

In China, raw night soil has been used as a very good source of organic manure for over 2000 years. It contains 1.2–1.3% N, 0.8–1.0% P_2O_5 , and 0.4% K_2O . In other countries like India, it is not directly applied to the soil, except in the villages where there are no adequate sanitary facilities or public latrines, and villagers go to fields and cover night soil with earth. In big villages, night soil compost is now been prepared and has been found to be the most convenient method of disposal of night soil. In some villages, however, night soil is dehydrated by mixing it with suitable materials such as dry soil, wood ash, or lime. Such a preparation is called poundrette. In some cases, pits or trenches 3–4 m long, 60–90 cm wide, and 22.5–30 cm deep, are dug, and night soil is deposited in this pit and covered on the top with a layer of earth. Saw dust and dry leaves to the extent of 50% by volume also serves as efficient material for mixing with night soil. The dry material is then taken out and piled in heaps to further dry in sun to give an odor-free manure containing about 2.5% N.

Human urine, which contains 1% N, 0.1–0.2%, and 0.2–0.3% of K_2O , is usually mixed with night soil but can also be collected separately from urinals, which may be set up in schools and public places. The liquid may be used as manure in sugarcane.

5.5 Sewage

Many municipal bodies in bigger towns operate sewage disposal systems. Sewage has two components, (a) solid portion known as sludge and (b) liquid portion known as sewage water. In other words, to avoid pollution of water in the streams by directly releasing sewage in them, the solid is separated, and the clear effluent is discharged in the streams. The solid portion is known as settled sludge. When it is digested anaerobically for a period of 10–15 days and dried in beds, it is termed as digested sludge. It has offensive odor, but it is free from pathogenic organisms. The sludge is richer than FYM in NPK content as well as micronutrients viz., boron, manganese, zinc, and iron, and contains on average 2–2.5% N, 1–1.2% P_2O_5 , and 0.4–0.5% K_2O . Passing air rapidly through raw sewage, which accelerates aerobic decomposition of the material, produces activated sludge, which has no offensive odor. After proper drying, it contains 8–10% moisture, 5–6% N, 3–3.5% P_2O_5 , and 0.5–0.7% K_2O .

When sewage is treated, the clear effluent is used for irrigation purposes. The effluent from the settling tanks with only anaerobic fermentation treatment still carry a large quantity of objectionable colloidal matter. However, with aerobic oxidation, the treated effluent is cleared, and odorless liquid containing nitrates in solution from which the greater number of pathogenic bacteria originally present has been removed. Some soils develop sewage sickness by continuous application of sewage water and have to be given rest. A soil with high pH generally becomes sick.

5.6 Sheep folding

In dry regions, where sheep and goats are reared to a large extent, sheep folding is a good source of nutrient supply. In some countries like India, sheep folding is practiced on a large scale because sheep are always moved from wet regions to dry regions. Just before the onset of monsoon in coastal district and other high rainfall areas, big herds of sheep are transferred to low rainfall areas in western districts. They are again moved back from December onwards. In their to and fro journey, shepherd usually allowed them to rest in cultivators' fields during night on payment made in kind. The manurial value of sheep folding is fairly high, and the cost of manuring is much less compared to other organic manures. Sheep dung and urine mixed contains 0.95% N, 0.35% P_2O_5 , and 1.0% K_2O .

5.7 Green manuring

Green manuring is defined as the practice of plowing-in the green plant tissues grown in the field or adding green plant with tender twigs or leaves from outside and incorporating them into the soil for improving the structure as well as the fertility of the soil. There are two types of green manuring:

1. Green manuring: When green manure crops are grown in the field itself either as pure crops or as an intercrop with the main crop and buried in the same field, it is known as green manuring in situ. The most common green manure crops are sann hemp (*Crotalaria juncea*), dhaincha (*Sesbania aculeana*), pillipesara (*Phaseolus trilobus*), and Juar (*Cyamopsis tetraganloba*). The practice of green manuring is adopted in various ways in different parts of world to suit the soil and climatic conditions. In some countries, green manure crop is grown in the field to be green manured and plowed-in. In other countries, it is grown with the

main crop and is trampled into the soil. Also, in other cases, it is grown on bunds and is cut and incorporated into the soil.

2. Green leaf manuring: Tender green twigs and leaves are collected from wastelands and nearby forest. They are spread in the field and incorporated into the soil. Shrubs and trees are also grown on bunds, and their green leaves and twigs are cut and turn into the soil. The common shrubs are glyricidia (*Gliricidia maculata*), *Sesbania speciosa*, and karanj (*Pongamia pinnata*) etc.

5.8 Other bulky organic manures

Some other bulky organic manures commonly used are as follows:

- a. Rice husk, which contains 0.3–0.5% N, 0.2–0.3% P_2O_5 , and 0.3–0.5% K_2O .
- b. Groundnut shells, which contain 1.6–1.8% N, 0.3–0.5% P_2O_5 and 1.1–1.7% K_2O
- c. PMC, which contains 1.0–1.5% N, 4–5% P_2O_5 , 2–7% K_2O , and 3–5% lime. It is also useful for reclaiming acidic and alkaline soils.
- d. Cottan waste, which contains 1–1.5%N, 0.4–0.8% P_2O_5 , and 1.6–2.9% K_2O .

6. Use of biofertilizers in soil fertility management

One of the major constrains in increasing sugarcane yield is the supply of nutrients, particularly NPK as well as secondary nutrients like silicon and sulfur and micronutrients too, considering the increased use of inorganic fertilizers in urea form, which is the cheapest form of N fertilizer. When the rate of application of NPK fertilizer is checked, it can be observed that due to distortions in selling price, the addition of NPK fertilizers is not done in a proper ratio of 4:2:1 as recommended. This has resulted in deterioration of soil, leading to saline and alkali soils and finally less fertile soils and, ultimately, decrease in sugarcane productivity. Considering the availability of N fertilizers, its leaching losses, high cost as well as the ill effects on soils, there is no alternative but to rely on the application of biofertilizers in addition to organic matter.

Under the present situation of increasing demand for fertilizer despite the high cost, it is essential to adopt an integrated nutrient supply, by using a judicious combination of chemical fertilizers, organic manures, and biofertilizers of microbial origin. Soil fertilizers play a prime role in sugarcane productivity, which in turn depends on the nutrient availability which is one of the indispensable factors for optimum plant growth.

Many factors affect soil fertility directly and indirectly, in which nutrient availability in readily available form for plant uptake, is most important. So, any element either major element or minor may be present in organic form or inorganic form, unless it is converted to specific form or supplied to plant in specific form, it is neither taken by the plant nor utilized for its developments.

Use of microbes as bio-inoculants in agriculture is not only economical but also beneficial so far because without intervention of microorganisms, one cannot imagine transformation of elements as well as recycling of elements in nature. So, besides the use of inorganic or organic fertilizers, use of microorganisms as biofertilizers has

become a must, to have our agricultural activities economical as well as without any side effects, to maintain soil fertility and increase crop productivity. These useful microorganisms, which are native to soil are originally present in soil but their number is less. To increase their work efficiency, their number should be increased by adding them externally in form of bio-inoculants/biofertilizers. Application of bio-fertilizers in the management of soil health and fertility in sugarcane cultivation has been done for over decades. But they are not popularized, due to various reasons such as quality of biofertilizers, their methods of application, visual results etc. Efforts are needed to popularize the use of biofertilizers in sugarcane with a greater vigor and support from government and non-government organizations. In general, the average yield of sugarcane can be increased by 11.4% through the use of biofertilizers.

6.1 What are biofertilizers

Biofertilizers are products consisting of selected, efficient, and beneficial live or latent (resting stage-spores) microorganisms, which help to improve plant growth and productivity mainly through the supply of plant nutrients (**Table 15**). Biofertilizers are also known as microbial inoculants or bio-inoculants. Biofertilizers have been introduced in agriculture for more than five decades in view of their cost effectiveness, contribution to crop productivity, soil sustainability, and eco-friendly characteristics. Biofertilizers form an integral part of integrated plant nutrient supply system (IPNS) and organic farming.

Microorganism's name	Nature of existence	Functions
<i>Azotobacter chroococcum</i>	Free living	Augment nitrogen to sugarcane, different cereals, and vegetable crops.
<i>Azospirillum</i>	Associative symbiotic	Augment nitrogen to sugarcane, maize, wheat sorghum, etc.
<i>Acetobacter diazotrophicus</i>	Endophytic	Augment nitrogen to sugarcane, maize, wheat sorghum, etc.
<i>Frateuria aurantia</i> <i>Bacillus subtilis</i>	Free living	Potash mobilization in soil
Mycorrhiza (<i>Glomus</i> spp.) VAM fungi	Symbiotic	Nutrient (phosphorus) mobilization
<i>Bacillus polymyxa</i> <i>Pseudomonas striata</i> <i>Aspergillus awamori</i>	Free living	Augment phosphorus to sugarcane and other crops.
<i>Pseudomonas fluorescens</i>	Free living. Soil pathogen inhibitor	Plant growth promoting rhizobacterium
<i>Thiobacillus thiooxidans</i>	Free living	Fe and S augmentation in soil
<i>Thiobacillus ferrooxidans</i> <i>Clostridium</i> and <i>Klebsiella</i> spp.	Free living	Zn and Cu availability in soil
<i>Trichoderma viride</i> <i>T. harzianum</i> <i>Gliocladium virens</i> <i>Chaetomium globosum</i> <i>Paecilomyces</i> sp.	Free living. Soil pathogen inhibitor	Compost enrichment. Acceleration of compost decomposition.

Table 15.
Beneficial microorganisms used as bio-inoculants in sugarcane cultivation.

Most of the biofertilizers presently manufactured are carrier-based (i.e., lignite or charcoal as carriers) in general and suffer from short shelf life, poor quality, high contamination, and low and unpredictable field performances. There are many constraints for using the biofertilizers [12], which include unavailability of good carrier in local area, quality inconsistency of carriers, supporting of poor cell number, short shelf life, poor moisture retention capacity, bulk sterilization problem in terms of economic and facility, inadequate storage capacity, pollution hazards from carrier dust, problem of proper packing, high transportation cost, instability to ambient temperature, labour intensive, and restriction on use as a measure of conservation.

6.2 Benefits of biofertilizers in sugarcane cultivation

1. Good germination, with germination percentage increasing from 8 to 22.5%
2. Cane yield is increased by 15–25%.
3. Improve the cane quality
4. Saving of 25% inorganic nitrogen fertilizer
5. Increases the availability and uptake of Nitrogen and Phosphorus in plants
6. Improve the status of soil fertility and productivity of crop
7. Increases the disease resistance in plants due to production of anti-fungal (fungi static) substances.
8. Recycling/transformation of elements from agro-industrial waste.
9. Secretes growth promoting substances and helps plant growth.

6.3 Nutrient availability through biofertilizers in sugarcane nutrition

Nitrogen is the most essential nutrient required in a fairly large amount for increased productivity of sugarcane and other cereal crops. It constitutes 1–5% of the plants dry matter and being a major component of protein and other compounds, which directs and controls the metabolic activity of the plant. It is a universal fact that atmosphere is highly rich in nitrogen (78% N) but without the aid of microorganisms, not a single molecule of atmospheric nitrogen can be utilized by plant. Microorganisms including bacteria, blue-green-algae etc., fix atmospheric nitrogen into ammonia by a process called biological nitrogen fixation (BNF) either symbiotically or non-symbiotically, and further nitrifying bacteria converts ammonia into nitrate, which is assembled by the plants.

The cost of inorganic fertilizers is increasing in recent years. Organic fertilizers being slow in releasing the nutrients, cannot supply nutrients to the plant in readily available form and hence use of useful microorganisms such as biofertilizers for making nutrients available to plants in readily available forms has become a must, along with the application of organic matter and simultaneously decreasing the dose of some of the inorganic fertilizers.

In sugarcane nutrition, where inorganic nitrogen is to be used by the plant as a nutrient, BNF and nitrification can serve for achieving the readily availability of

nitrogen in a specific form known as “Nitrate.” BNF is the process which involves the intervention of microorganisms, which converts atmospheric nitrogen into ammonia, and thus, nitrogen that is free-of-cost present in atmosphere is fixed for further conversion into nitrate through nitrification process, which is taken up by the plants, and all these processes are carried out by microorganisms known as nitrogen-fixing and nitrifying bacteria, respectively. Thus, by using these microorganisms, the doses of inorganic nitrogen fertilizers can be reduced, and at the same time, the fertility of soil can be maintained.

In this connection, BNF microorganisms have been found to meet efficient supplementary sources of nitrogen against the chemical fertilizers [13, 14]. So, BNF has become an economically advantageous process in sugarcane nutrition. Nitrogen-fixing microorganisms convert about 139–170 million tons of nitrogen every year into available form that is plant usable. It is at least several folds greater than the input of nitrogen from chemical fertilizer to the tune of 65 million tons per year. The fact that the total world BNF is three times that of inorganically fixed nitrogen indicates the significance of BNF in sugarcane cultivation. Thus, BNF system offers an economically attractive and ecologically sound means of externally reducing external inputs and improving internal resources. *Beijerinckia*, *Azotobacter*, and *Azospirillum* can fix atmospheric nitrogen non-symbiotically or associative symbiotically and all are exophytic and fix nitrogen in rhizosphere of crop.

In sugarcane crops, endophytic bacteria like *Acetobacter*, *Herbaspirillum*, *Agrobacterium*, *Azoarcus*, *Azospirillum* etc., play a major role in BNF process as well as they produce plant growth promoting and regulating substances (PGPR). In sugarcane nutrition, *Acetobacter diazotrophicus*, an endophytic bacterium, which is present in all parts of the plant including stem, leaves, root, juice etc., and actively participates in BNF process by fixing 2–3 times more nitrogen (up to 200 kg N/ha) as compared to *Azospirillum*, thus fulfilling the requirement of N fertilizer. To increase work efficiency of these bacteria when applied externally either by sett inoculation or foliar application, it fixes nitrogen in plant itself. *Acetobacter* is Gram-negative, microaerophilic bacteria, motile with lateral flagella, present in high number in roots and stems and shows optimal growth with 10% sugar and pH around 5.5 precisely this condition prevailing in sugarcane. It is also an efficient microaerobic N₂-fixing bacterium, which is able to fix nitrogen in presence of nitrate as it does not possess Nitrate reductase, which may lead to complementation of Nitrogen fixation with fertilizer application. For achieving high sugarcane yield, application of *Acetobacter diazotrophicus* as bioinoculant @ 10 kg/ha as sett treatment for 30 min. in 100 lit. of water is recommended for saving of 50% nitrogen.

Next to nitrogen as an important nutrient in sugarcane nutrition is phosphorus, which is vital and non-renewal nutrient for plants and microorganisms. It helps for better growth of root system and maximum crop productivity. A majority of soils worldwide are poor in available phosphorus and efficiency of phosphorus fertilizer utilization by crop plant is about 10–15%. When phosphorus is applied to soils, it becomes immobilized due to fixation with ions like Ca, Al, and Fe as calcium phosphate in neutral to alkaline soils while as ferrous sulphate or aluminum sulphate in acidic soils. Phosphorus may be present in inorganic or organic forms, and unless it is solubilized by microorganisms, it is not taken up by plants. Phosphate-solubilizing microorganisms like *Bacillus*, *Penicillium*, *Aspergillus* as well as vesicular arbuscular mycorrhizae (VAM) etc., solubilizes the insoluble form of phosphorus and avoids the immobilization of phosphorus.

Sulfur is one of the 16 essential elements required for good growth and development of sugarcane. Sugarcane requirement of sulfur is comparable to that of

phosphorus and therefore now considered to be the fourth major element required for the plant growth [15]. Sulfur plays an indispensable role in the synthesis of amino acids, chlorophyll formation, and metabolic activities of the plant. Its deficiency causes impairment of synthesis of chlorophyll, which results in the formation of pale yellow or light green leaves in sugarcane. Sulfur is present in both organic and inorganic forms in soils but largely in organic form, and unless it is converted to sulphate form, it is not utilized by plants [16, 17]. Mineralization of sulfur present in organic matter as well as oxidation of inorganic form of sulphur are carried out by microorganisms only. Among these, Sulfur-oxidizing microorganisms like *Thiobacillus*, *Thiothrix* and *Tioplaca* as well as fungi and Actinomycetes like *Penicillium*, *Aspergillus*, *Microsporium* carry out oxidation of sulphur.

Sulfur deficiency was not impediment in crop productivity, but in an intensified agriculture due to high yielding varieties of sugarcane, increasing cropping intensity, use of sulfur free fertilizers, limited supply of organic manures and great leaching losses of sulphates from the soil have depleted soil S reserve causing emergence of sulfur deficiency. Hence, to overcome 'S' deficiency, the addition of a suitable form of sulfur with sulfur-oxidizing microorganisms has become almost essential. Different form of sulfur like elemental sulfur, ammonium sulphate, phosphogypsum, pressmud-cake etc., are found to be equally beneficial, but in alkaline calcareous soils, elemental sulfur and ammonium sulphate whereas in coarse textured soils, phosphogypsum and PMC are more useful.

Agro-industrial wastes like PMC and spent wash serve as good sources of sulfur in addition to other elements. During sugar processing, sulphitation process adds sulfur to the cane juice which further remains in PMC and spent wash in forms like CaSO_3 . Compost prepared from these biproducts can serve as good source of sulfur-to-Sulfur oxidizers and further, it can be made available to plants by oxidation to sulphate. Thus, reutilization of these biproducts not only helps in reutilization of sulfur but also other essential elements required by the plant present in it [18]. It has been found that sulfur application @ 60 kg/ha in two equal splits, i.e., before planting and at earthing up along with sulfur-oxidizing microorganisms increases cane and sugar yield by 21.2 and 21.1%, respectively.

Sugarcane being a nutrient exhausting crop [19] and due to intensive cropping of high-yielding varieties of sugarcane without rotation of crop, scarcity of organic matter, addition of improper dose of inorganic fertilizers, heavy irrigation etc., most soils become saline and alkali. So, reclamation of such soils can be expedited with help of addition of elemental sulfur and sulfur-oxidizing microorganisms. In process of reclamation, sulfur-oxidizing microorganisms utilize sulfur to sulphate which decrease the pH of the soil. Thus, sulfur-oxidizing microorganisms play a vital role in reclamation of problematic saline and alkali soils [20].

Next to sulfur as secondary element is silicon (Si), though called as functional element, plays a crucial role in sugarcane nutrition. There are some functional nutrients though they are non-essential elements, that under certain agroclimatic conditions, enhance the plant growth by promoting several physiological processes. For example, for sugarcane crops, Si is such an element. It absorbs more Si than any other mineral nutrient, accumulating approximately 380 kg/ha of Si, in a 12-month old sugarcane crop.

The accessibility of Si to sugarcane largely depends on how quickly weathering takes place to release Si to soil solution. The prevailing form of silicon in the solution is monosilicic acid (Si(OH)_4), which is the absorbed form by plants. Although silicon is not considered as essential element for all the crops, it plays a crucial role

in graminaceous crops like rice, oats, barley, maize, sorghum and sugarcane. Si is considered as a beneficial element, which has a number of roles in amino acids and protein metabolism. However, Si has well recognized beneficial effects on sugarcane growth. In plant supplied with sufficient amount of Si, cuticular water loss has been found to be lowered because of the epidermal accumulations of silica. Si also affects lignin biosynthesis and provides resistance to sugarcane against biotic and abiotic stresses.

Silicon has diversified role in plants as well as in soil. When silicate materials are applied to the soil with high P fixing capacity, it reduces the P fixation, and P content in the labile pool. This fact could be attributed to the release of more soil P in the replacement of adsorbed phosphate ion by silicate ion. It can also be applied to organic soils, which are deficient in silicon. It can also alleviate Al and Fe toxicity in acid soils because of its possible anion uptake and of expels equal amount of OH ion from the roots, which can increase the soil PH at the root surface and eventually affect the uptake of Al and Fe.

Silica generally influences the physiology of sugarcane as it has a functional role in plant metabolism. Supply of silica increases leaf area, which decreases the photosynthetic activity of the lower leaves and thus enhances the photosynthetic capacity. It also promotes the oxidation power of plant roots and thus alleviates the toxicity of H₂S and harmful effect of excess Mn and Fe, which may occur in plant tissues. As a result, the accumulation of brown spots surrounded by chlorotic and necrotic areas has been found to be absent due to silicon supply. In the absence of Si, considerable reduction in the incorporation of inorganic phosphate to adenosine diphosphate (ADP), adenosine triphosphate (ATP), and sugar phosphates has also been reported in sugarcane. Si also plays an important role in the water economy of plant where Si-free plants suffer from internal water stress when they are grown in conditions where the rate of transpiration is greatly increased or absorption of water is greatly reduced.

Scarcity of organic matter in soil is one of the main reasons for soil deterioration. Soil fertility management especially for biological fertility through the use of agro-industrial wastes as organic manure with different microorganisms besides basal dose of NPK in sugarcane farming has become almost essential to avoid nutrient deficiency. Artificially multiplied cultures of selected microorganisms as bio-decomposers play a part in accelerating natural way of recycling of organic resources that can be very much useful in sugarcane nutrition.

Decomposing microorganisms play a crucial role in the decomposition of organic matter and ultimately in the recycling of nutrients exhausted from the soil. Sugarcane bi-products right from trash to spent wash contains many essential nutrients, which are exhausted from the soil and unless recycled to the soil can lead to deficiencies in next crop of cane. This type of soil fertility management to avoid such deficiencies, can be achieved through the application of inorganic or organic fertilizers.

Due to the scarcity of organic manure and slow release of nutrients, its use in agriculture is very less. So, at present, for soil fertility management, farmers mainly rely on inorganic fertilizers and are using excess doses to get maximum cane yield. But the use of these fertilizers does not achieve the actual purpose of soil fertility management, rather it leads to deterioration of soil fertility and decline in crop yield. Decomposition of agro-industrial wastes through composting by use decomposing microorganisms like *Bacillus subtilis*, *Trichoderma viride*, *Aspergillus niger*, *Penicillium chrysogenum*, *Chaetomium* sp., and *Actinomycetes* species, has become most imperative to maintain soil health and fertility.

Sugarcane being a high-nutrient exhausting crop, to achieve targeted yield as well as to maintain soil health and fertility, the use of balanced or recommended doses of inorganic fertilizers, organic manures supplemented with biofertilizers has become relevant and of economic importance. Because it is a well-established fact that whether nutrients are present in organic or inorganic form, unless they are converted to “readily available” forms, are not taken up by the plants for their growth and such bioconversions of these elements are carried out by nothing else but microorganisms. These decomposers include bacteria, fungi and actinomycetes. Decomposition process requires lot of manual efforts including transportation of the wastes but labour availability is becoming a problem nowadays. So, farmers prefer readily available inorganic fertilizers to composting of these agricultural wastes though there are lot of detrimental effects of these inorganic fertilizers besides their cost. But to maintain soil health and fertility for long term, again farmers need to rely on organic manure only, which is available at free of cost but for this, farmers have to adapt an easy, effective and quick method of decomposition.

Sugarcane crop after harvest leaves about 8–10 MT of sugarcane trash/ha. So, considering approximately vast area under production, about several million MT of trash is generated every year. Most of the trash is burnt off after harvesting and the elements exhausted from soil which are present in trash are wasted. Trash contains 0.43% N, 0.18% P_2O_5 , and 0.68% K_2O and 39–46% organic carbon. It also contains high lignin and cellulose content. Decomposition of sugarcane trash in ratoon crop will help decomposing microorganisms to produce good quality composts within three and half months, thus saving labour and transportation cost.

In most of the sugar factories, the pressmud cake is being used as a source of organic matter because of its high organic carbon content and as a soil ameliorating agent. It contains 1–1.5% N, 4–5% P_2O_5 and 0.4–0.5% K_2O and 33–36% organic carbon. It also contains 8–15% wax, so its direct application in the field may affect the soil structure. Spent wash is another industrial effluent, which contains dissolved solids, mineral salts and high biological oxygen demand (BOD) (40,000 ppm). So, its direct application in the field is objectionable. However, it contains 28–36% organic carbon, 1.89% N, 0.26% P_2O_5 , and 9.45% K_2O on solid basis. Considering the importance of by-products of sugar industries viz., PMC, spent wash, ash, sugarcane trash etc., composting of these agro-industrial wastes into valuable organic manures can be achieved by using decomposing microbial cultures.

7. Conclusion

Sugarcane is one of the high nutrient demanding crops, and its cultivation depletes the soil more rapidly, and eventually yield will be depressed if nutrient supplements are not adequately provided. Its sustainable production is only possible through proper use of inputs that maintain the soil fertility. The gravity of environmental degradation caused by faulty and intensive agricultural practices has become evident, and there is increasing pressure to develop ecologically sound, viable, and sustainable soil fertility management practices specifically through integrated nutrient management. Integrating biofertilizers, organic manures, appropriate and balanced use of chemical fertilizers, and modern soil management techniques such as the management of problematic soils improves the soil fertility for optimum growth, yield and quality of sugarcane. Integrating biofertilizers and modern soil management techniques can reduce nutrient losses from applied inorganic fertilizers,

increase soil nutrient retention, and serve as alternative or supplementary sources of major nutrients. The application of fertilizers based on demand of crops, as per soil test crop response program, at proper timing and placement of fertilizers with controlled release of nutrients and proper choice of crops are the important features INM. Biofertilizers like acetobacter, azotobacter, phosphorous solubilizing bacteria and fungi, rhizobium, and VAM when used as alternative sources of N and P have good promises of restoring and sustaining soil fertility and improving sugarcane crop productivity. Integrating organic manures such as FYM, compost, vermicompost, poultry manure, oil cakes (e.g., castor and neem cake) together with good crop residue management, green manuring, incorporating legumes as intercrop can improve the physicochemical and biological properties of soil, and ultimately crop yield. Future research should be directed towards the assessment of on-farm resource availability, soil test-based nutrient requirement, integration of nutrient sources and establishment of time, method of application by adopting appropriate soil and water conservation techniques. This can be applicable to a wider range of landforms and sugarcane crop varieties.

Author details

Denis Magnus Ken Amara^{1*}, Melvin Sidikie George², Osman Sidie Vonu³, Sheriff Bangura¹, Emmanuel Alpha³, Foday Saidu Sesay¹, Alpha Sheku¹, Abu Bakarr Conteh¹, Samuel Josie Domingo¹, Michael Jusu⁴ and Foday Turay⁵

1 Department of Soil Science, School of Agriculture and Food Sciences, Njala University, Sierra Leone

2 Department of Crop Science, School of Agriculture and Food Sciences, Njala University, Sierra Leone

3 Department of Agronomy, Eastern Technical University of Sierra Leone, Sierra Leone

4 Department of Agricultural Education, Eastern Technical University of Sierra Leone, Sierra Leone

5 Department of Agricultural Engineering, Eastern Technical University of Sierra Leone, Sierra Leone

*Address all correspondence to: dmkamara@njala.edu.sl

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