Review Article

Soil conditioners: Refinement of soil health for better tomorrow

Abstract

In the present era, we can see an overabundance of fertilizers and more focus on chemical inputs. The extensive use of fertilizers has resulted in a worldwide issue of soil degradation, causing the reduction of organic material and soil fertility. At the same time, farming is getting more intense as cities grow and industries expand. This is making more and more waste. As an example, mining for coal makes a lot of waste all over the world, and most of this waste is put into landfills or special ponds. This is where sustainable food production comes in. People all around the world are coming up with new ideas to use waste in a good way to make useful things, like stuff that can improve soil. In the present era, soil conditioners are highly valuable for enhancing both plant growth and soil well-being, simultaneously reducing the need for chemical fertilizers. Any procedure that enhances a soil's capacity to improve crop yields, or that betters the soil's effectiveness for any purpose, can be termed as soil conditioning, and any substance used in soil conditioning is referred to as a soil conditioner. Soil necessitates conditioning for various reasons, with a key objective being the management of soil degradation, improve soil's air-water interactions, drainage capability, and aggregation. This process also aims to mitigate issues like compaction, soil crusting, and water repellency. Soil conditioner surrounds a wide range of substance, such as organic materials, gypsum, lime, diverse water-soluble polymers, natural deposits, and cross-linked polymers that retain soil moisture. It also includes living plants, microbes, various industrial waste products, and similar items. Soil conditioners offer utility by enhancing the soil's functionality as an ecosystem and improving its efficiency in providing support for crop growth.

Key Words: soil fertility, humates, soil degradation, nutrient availability, organic conditioners, C: N ratio.

Introduction

Present population is forecasted to outreach 9.6 billion by 2050, however, the present agricultural production levels would need to increase by 70 per cent in order to feed such outnumbered population (Shubham *et al.*, 2023).Conventional agricultural practices, characterized by extensive use of fertilizers and pesticides, have undeniably contributed significantly to fulfilling global food demands. However, this achievement has come at a cost – the degradation of soil quality, diminished fertility, reduced crop yields, and compromised ecosystem health. The decline in soil productivity can be attributed to various physical limitations such as surface crusting, subsurface compaction, impermeability, and susceptibility to erosional forces like wind and water. In light of this, it becomes critical to cultivate a soil environment conducive to healthy crop growth if we aim to bolster agricultural output. Indeed, the careful management of soil's physical health has the potential to substantially elevate the yield capabilities of diverse crops. In this pursuit, the integration of organic and inorganic soil conditioners and additives emerges as a promising strategy to rehabilitate agricultural land and enhance productivity.

Soil conditioning encompasses methods and substances that heighten a soil's aptitude to nurture thriving crops or amplify its efficacy in performing various functions. Materials utilized for soil conditioning – known as soil conditioners – typically contain minimal nutrient content. Their primary utility lies in their favourable influence on the biological, physical, or chemical attributes of the soil. These substances can also serve as growth mediums for plants. Within the realm of soil conditioning, a pivotal aspect involves the creation and stabilization of soil aggregates conducive to seed germination and seedling emergence. An effective soil stabilizer for these roles must fortify aggregates against disintegration caused by raindrops, while concurrently maintaining robust water infiltration capabilities (Gabriels *et al.,* 1981).

The realm of soil conditioners encompasses a diverse array of organic matter, gypsum, lime, naturally occurring deposits, water-soluble polymers, cross-linked polymers that enhance soil water retention, living flora, microorganisms, various industrial byproducts, and more. Despite the contemporary prevalence of fertilizers and the emphasis on chemical inputs, the significance of soil conditioners and amendments often remains underestimated (Shubham *et al.*, 2022). Proper soil conditioning serves multifaceted objectives, including arresting soil degradation, enhancing soil-water relationships, optimizing drainage and aggregation, combating compaction and crusting, addressing water repellence, and more. When evaluating the role and impact of soil conditioners in crop production, it's vital to recognize that the addition of such materials can exert both positive and negative effects on numerous soil properties. These encompass, among others: (1) the soil's capacity to retain water, (2) aeration levels, (3) temperature regulation, (4) nutrient retention and availability, (5) cation exchange capacity (CEC), (6) structural integrity and aggregate stability, (7) behaviour and population of microorganisms, (8) chemistry of organic matter, and (9) interactions with animals, including insects and pests. In essence, the judicious implementation of soil conditioners holds the potential to foster sustainable agricultural practices by ameliorating soil quality and bolstering crop yield.

Soil conditioners

Soil conditioners are special materials that have important nutrients. They help make soil better for plants by fixing its problems. These materials can be natural things like plants and microbes, or man-made substances like polymers and industrial waste products. Soil conditioners improve the soil's physical, chemical, and biological properties, making it great for plants to grow. They're like helpers for the soil, making it a good home for plants and helping them grow well.

Soil conditioners are substances containing vital nutrients that enhance the soil physical, chemical and biological characteristics. They also promote plant growth and vitality by addressing deficiencies in soil structure and nutrients simultaneously used for this motive are compost, FYM, inexperienced manure, peat moss, humates, gypsum, fly ash, lime, and so on.

Significance and role of soil conditioners

- They play a crucial role in regulating soil pH, particularly in challenging soils such as acidic or alkaline ones.
- Soil conditioners enhance the soil's physical, chemical, and biological attributes.
- In arid and sandy soils, soil conditioners ameliorate water retention, infiltration, percolation, and overall water permeability.
- Soil conditioners elevate physical qualities, leading to improved soil aeration, enhanced water-holding capacity, better root growth, and a thriving soil ecosystem.
- By fostering a favourable soil environment, soil conditioners attract beneficial microorganisms and earthworms that contribute to soil health.
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- Their utility extends to the revitalization of impoverished soils and the restoration of soils damaged due to improper management.
- Nutrient enrichment is another benefit; soil conditioners introduce essential elements, nurturing healthier and more productive plant growth.
- Soil compaction and the formation of hard layers are mitigated by the application of soil conditioners, counteracting the compression that occurs over time.

- The augmentation of soil fertility is a direct outcome, sustaining soils in a state of optimal health and functionality.

Types of soil conditioners

The soil conditioners can be classified on the basis of two criteria:

1. Origin of the materials.
2. Composition of the materials.
   Soil conditioners come in two types based on where they come from.They can be either man-made (synthetic) or found in nature(natural). Also, in terms of what they are made of, soil conditioners are classified as organic or inorganic materials.

1.Organic conditioners

Organic soil enhancers are derived from living organisms such as plants andanimals, and they serve to enhance soil quality by promoting moisture retention, fostering soil microorganisms, and enhancing soil structure. These enhancers originate from materials like compost, agricultural residues, and animal byproducts. They contribute to the soil's capacity to retain moisture, prevent compaction, and maintain optimal texture. Organic enhancers, such as compost and peat, are widely used and highly beneficial for maintaining soil health.

The proportion of carbon to nitrogen (C:N ratio) in organic matter within surface soils typically falls between 8:1 and 15:1, with a median range of 10:1 to 12:1. The C:N ratio of organic materials (Table 1) added to the soil plays a crucial role in nitrogen availability and the speed at which the organic material decomposes.

Table 1. Approximate C:N ratios of organic material and soil microbes (Follett *et al.*, 1981)

Material	**C:N Ratio**
Crop Residues	

Clovers (mature)	20:1
Corn Stalks	40:1
Alfalfa	13:1
Bluegrass	30:1
Starw (small grain)	80:1
Sewage Sludge	10-12:1
Peat Moss	58:1
Cattle Manure	30:1
Sawdust Based Soil Conditioners	
Hardwood	295:1
Pine	729:1
Microbial based Soil Conditioners	
Fungi	10:1
Actinomycetes	6:1
Bacteria	5:1

A) Composts: When microbes decompose organic material, compost is formed in the presence of oxygen. As a soil conditioner, composting has a variety of advantages, including a rise in organic C content and microbial activity, a source of plant nutrients including N, P, K, and Mg, and a strengthening of the roots(Donn *et al.*, 2014; Shubham *et al.*, 2022). A significant attribute of compost is its ability to impact the soil's microorganisms, which includes the suppression of various soil-borne pathogens like Pythium, Phytophthora, and Fusarium species. Consequently, the utilization of compost typically sustains and improves the stability and fertility of agricultural soil (Zhou *et al.*, 2016). Compost, which is like a rich natural fertilizer, is a common organic conditioner. Other examples include leftovers from crops, animal waste, and materials like peat and coffee grounds. These materials make soil healthier and helpplants grow strong.

B)Farmyard manure (FYM): FYM, or Farm Yard Manure, is a natural compost made from animal dung, urine, and bedding material that breaks down over time. It's rich in nutrients and boosts soil quality by adding organic material. This helps the soil in various ways, making it better for plants to grow(Gore *et al.,* 2011[ab]).It can be used with any sort of crop or soil that has issues.

C)Green manures: Green manures are cultivated crops primarily intended to enrich the soil with nutrients and organic material. They are sown in alternation with other crops, plowed under, and integrated into the soil to fulfill the same roles as conventional manures. Green manures play a crucial role in fostering the resilient soil structure essential for nurturing plant growth and development. They stimulate soil aeration, improve drainage, and encourage the formation of soil aggregates, leading to heightened microbial activity and enhanced soil fertility (Shinde *et al.,*2017).

D)Crop residues: Crop residues represent the plant matter that remains in agricultural fields or orchards following crop harvesting. These residues encompass elements like stalks, stubble (stems), leaves, and seed pods. They serve as a valuable source of organic material that can be reintegrated into the soil to facilitate nutrient recycling and enhance the physical, chemical, and biological characteristics of the soil. Therefore, incorporating crop residues into the soil enriches nutrient cycling, promotes soil and water conservation, and ultimately leads to increased crop yields (Grace *et al.,* 2013; Sharma *et al.,* 2014; Shinde *et al.,* 2019).

E)Sewage sludge: Sewage sludge, or biosolids, is organic material from sewage that's treated to remove bad smells and make it safe from pests and diseases (Goss *et al.,* 2013). Biosolids, which have nutrients and organic material, can be used in farming, but rules are in place. These rules control the amounts of metals, weeds, and harmful substances for both people and plants.

F)Peat Moss: Peat is made from plants that haven't fully broken down. It's found in places like bogs and moors. Peat forms in certain conditions where plants can't decompose completely. When added to soil, it helps the soil hold more water and makes it better for plants to grow.

G)Humates: Humates are extraordinary natural substances that play a crucial role in enhancing soil quality and promoting plant growth. These compounds are derived from oxidized lignite, a material associated with coal deposits, and they are ancient organic materials present in the Earth. Unlike peat, humates have undergone extensive decomposition and mineralization, rendering them a rich source of plant nutrients. Humic acid, a key constituent of humates, makes up to 35% of their composition. Humic acids act as potent chelators, enabling them to bind essential nutrients in a form readily absorbed by plants. This remarkable capability renders humates invaluable for enhancing soil fertility.

H)Blood meal: It's a natural fertilizer and animal feed produced by grinding blood, which is rich in nitrogen. This powdered product is predominantly derived from the blood of calves or hogs slaughtered in abattoirs and has not undergone any artificial manufacturing processes.

I) Biochar: Biochar is a solid, fine, granular, and black material produced by slow pyrolysis of biomass, which is frequently derived from agriculture or forestry. Because of its vast surface area, negative charge, and high density, it attracts and holds nutrients in the soil, which benefits microbes and plant roots. Biochar improves soil aeration and microbiological activity by stabilizing natural resources. It also aids in the capture of nitrogen, which reduces the release of greenhouse gases such as methane, carbon dioxide, and nitrous oxide.

J) Used coffee grounds: It symbolizes the culmination of the coffee brewing procedure, arising from coffee extraction. These grounds hold a significant sugar content, accounting for about half of their total weight. An additional 20% is composed of proteins, while the remaining 20% is comprised of lignins. Dry coffee grounds are abundant in magnesium, potassium, phosphorus, and nitrogen. Given their gradual release of nitrogen into the soil, they can be effectively employed for composting or as mulch.

Inorganic soil conditioners

Using inorganic soil conditioners means enhancing the physical qualities of the soil, allowing better use of soil and water resources. These soluble inorganic conditioners react with soil components, particularly clay. Applying various conditioners like VAMA, Krilium, PVA, and Hygromull (a urea-formaldehyde soil conditioner) leads to improved soil structure, making it more porous and permeable. This process reduces soil density and enhances infiltration, allowing the soil to hold more water in its profile. In essence, these treatments significantly improve the soil's overall quality, making it more effective for agricultural purposes (Doyle *et al.,* 1960; Nimah *et al.*, 1983).

A) Mineralconditioners: This particular conditioner is employed for reclaiming polluted soil. Examples of such materials include Gypsum, lime, sulfur, crushed rocks, dolomite, and others.

i)Gypsum: Gypsum, with its moderate solubility, provides essential nutrients such as calcium and sulfur, fostering the overall growth of plants. One of its remarkable traits is its ability to substitute sodium in sodium-rich soils. Gypsum is used to restore sodic soil, saline areas, and compacted grounds by breaking down resilient alkali layers (Deshpande*et al.*,2011). Additionally, it supplies calcium to soils with limited capacity for exchange and enhances drainage in specific waterlogged soils, enhancing the health and growth of plants. Moreover, it enhances the physical, chemical, and biological attributes of soils (Gore *et al.*, 2011[b]). This improvement aids in reducing soil erosion and lowering nutrient concentrations, particularly phosphorus, in surface water runoff.

ii)Lime: The inorganic minerals that makeup lime, which mostly consist of oxides and calcium hydroxide, include between 75 and 95 percent calcium carbonate ($CaCO_3$). It is used to restore soil pH equilibrium in severely acidic soils. Additionally, to raising soil pH, it serves as a supply of calcium. When a soil's pH is too low (below 6.0), the soil has a difficult time absorbing nutrients, including those from fertilizers. This is where lime comes in particularly handy.

iii) Fly ash: Thermal power facilities produce fly ash as a byproduct. It is utilized as a soil amendment as well as a plant nutrient source. Fly ash has the potential to boost agricultural productivity and soil fertility. It not only boosts crop growth and output in low-fertility soils, but it also mobilizes macro and micronutrients.

B)Othermineral conditioners: Limestone, Dolomite, Crushed rock, Elemental sulfur, and similar products rich in calcium and magnesium are effective in enhancing the physical quality of challenging soils when applied at substantial quantities per acre.

i)Synthetic binding agents: These polymers are promoted for their role as soil conditioners but are applied in significantly lower quantities. These are composed of long-chain organic polymers with high molecular weights that efficiently unite soil particles, creating durable aggregates. Organic polymers, particularly polysaccharides (PSD) and polyacrylamides are employed to improve the stability of these aggregates, enhance soil fertility, and diminish soil sealing (PAM). Even small amounts of these polymers (10-20 kg/ha), whether applied by spraying directly onto the soil surface or mixing them with the irrigation water, have proven effective in the consolidation and bonding of soil aggregates at the surface. This process aids in preserving soil fertility, particularly in soils with high levels of exchangeable sodium (ESP >20). These polymers encompass anionic, catalytic, and non-viable variants.

ii) Cationic polymers: Clay absorbs cationic polymers like polyvinyl chloride (PVC) and polyphenol hydrochloride (PPH) through a process called cation exchange, where calcium acts as a bridge between clay particles and the polymers. These cationic polymers possess strong flocculating abilities.

iii) Anionic polymers: Hydrolyzedpoly-acryl-o-nitrile (HPAN) and vinyl acetate-maleic acid (VAMA) copolymers fall under the category of anionic polymers. They are utilized to prevent the crusting of highly sodic soils. These anionic polymer peripheral complexes establish a series of hydrogen bonds that interconnect the clay lattice in an edge-to-edge configuration. While they do not possess flocculating properties, they play a role in stabilizing already-formed clay aggregates. They adhere to the surface of dispersed particles, binding them by creating a bridge-like connection between them.

iv) Non-ionic soil conditioners: Polyvinyl alcohol (PVA) can form intermicellar complexes with expanding lattice-type clay, leading to the inhibition of swelling and improving the stability of soil aggregates through polymer coating within the pores.

v)Polyacrylamide: Polymeric soil conditioners have been familiar to agriculture since the 1950s. These synthetic polymers were designed to enhance the soil's physical characteristics, with the primary goals of reducing surface sealing, promoting seedling emergence, and mitigating issues such as runoff, erosion, and the leaching of fertilizers and pesticides. They function as synthetic binding agents and prove particularly valuable for assessing the physical quality of coarse-textured soils, which often suffer from diminished quality due to a high percentage of macrospores.

Effects of soil conditioners on soil properties: The intensification of agriculture results in significant quantities of agricultural waste, which can be utilized as sources for soil conditioning in sustainable farming practices. Both natural and synthetic soil conditioners can have a significant impact on the soil's physicochemical biological characteristics. Plant by-products are vital for recycling important plant nutrients, maintaining soil fertility, and lowering the toxicity of some heavy metals. ultimately leading to increased yields.

Purpose of soil conditioners

1) Soil structure: This compaction restricts root development, diminishing a plant's capacity to absorb essential nutrients and water. Soil conditioners are employed to introduce added volume and texture, ensuring that the soil remains loose and conducive to plant growth.

2) Enhancing Water Retention: Soil conditioners increase the soil's water retention capacity, ensuring that plants have consistent access to moisture, especially in dry periods.

3) Balancing Soil pH: Conditioners can adjust soil pH, making it more acidic or alkaline as needed for specific plants. Proper pH levels are crucial for nutrient availability.

4) Increasing Nutrient Availability: Soil conditioners facilitate the release and availability of essential nutrients to plants. They can also prevent nutrient leaching, ensuring efficient use of fertilizers.

5) Encouraging Beneficial Microorganisms: Conditioners promote the growth of beneficial microorganisms, enhancing the soil's biological activity. These microbes aid in nutrient cycling and improve soil health.

6) Mitigating Erosion: Soil conditioners, through the enhancement of soil structure and the encouragement of plant growth, play a vital role in mitigating erosion. This protective function helps safeguard landscapes and preserve soil fertility.

7) Promoting Sustainable Agriculture: Conditioners play a key role in sustainable farming by improving soil fertility, lessening reliance on chemical treatments, and fostering long-lasting soil well-being.

Effect of soil conditioners on soil properties and crop growth

Soil pH: Maintaining the right soil pH is a critical factor for achieving and sustaining high crop yields because it significantly affects metal toxicity, nutrient availability, and the soil microbial community (Zhao *et al.,* 2022). Previous research has indicated that applying supplements to acidic soils can increase soil pH, albeit the effect varies widely depending on the amendment used (Siedt *et al.,* 2021; Zhao *et al.,* 2020). Soil conditioners can influence soil pH in various ways. For acidic soils, agricultural lime, a common soil conditioner, is applied to raise the pH, making the soil more neutral. On the other hand, elemental sulfur is used to lower the pH of alkaline soils. Organic matter in soil conditioners acts as a buffer, stabilizing pH levels and preventing drastic fluctuations. Proper pH balance is vital because it affects nutrient availability; certain nutrients are more accessible to plants within specific pH ranges. Soil conditioners help maintain this balance, ensuring optimal conditions for crop growth.

Yield Response: Soil conditioners play a vital role in enhancing crop production through various mechanisms. They create a conducive environment for plants to efficiently acquire essential nutrients by adjusting soil pH to optimal levels. This pH regulation promotes strong root development and maximizes nutrient uptake. Furthermore, soil conditioners improve soil structure, preventing compaction and enabling deeper root penetration. This, in turn, enhances aeration and root growth, leading to better absorption of water and nutrients. Additionally, these conditioners bolster the soil's capacity to retain water, ensuring a consistent moisture supply to plants, even during dry periods. By nurturing a nutrient-rich, well-structured, and adequately hydrated soil environment, soil conditioners positively influence crop yields, ultimately fostering the growth of healthier and more productive plants.

Effect of Soil Conditioners on Nutrient Availability

Soil conditioners, through various mechanisms, enhance the availability of nutrients in the soil, ensuring plants receive the vital elements necessary for healthy growth. These enhancements contribute to improved agricultural productivity and overall soil health.

1. **Balancing Soil pH:** Soil conditioners play a pivotal role in adjusting the soil's pH levels, ensuring essential nutrients are readily absorbed by plants.
2. **Boosting Cation Exchange Capacity (CEC):**Conditioners enhance the soil's CEC, improving its capacity to hold and exchange nutrients effectively. This prevents nutrient loss and ensures a consistent nutrient supply for plant roots.
3. **Encouraging the Natural Breakdown of Organic Matter:**Several soil conditioners contain organic materials that naturally decompose, releasing essential nutrients into the soil. This process enriches the soil with vital elements crucial for strong and healthy plant growth. Promoting Beneficial Microbial Activity: Conditioners stimulate the growth of helpful microorganisms. These microbes further break down organic matter, releasing nutrientsin

forms easily absorbed by plants. They also contribute to nutrient cycling, maintaining a steady nutrient supply.

4. **Preventing Nutrient Fixation:** Soil conditioners stop certain nutrients from becoming fixed in forms inaccessible to plants. By maintaining nutrients in a soluble state, they facilitate efficient absorption by plants, ensuring optimal growth.

Conclusion

In response to the increasing need for food crops and agricultural product in our limited geographical areas, it is crucial to advocate for the widespread use of soil conditioners and the implementation of conservation techniques in farming. Soil conditioners provide significant benefits by enhancing the ecological functions of the soil and improving its ability to mature crops efficiently. Before applying both inorganic and organic soil conditioners, it is essential to thoroughly comprehend the unique needs and specifications of the land in question. This understanding ensures that the chosen soil conditioning methods are tailored to the specific requirements of the soil, optimizing their effectiveness. By adopting this approach, we can address the growing demand for agricultural goods while maximizing the productivity of our constrained land resources.

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