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Mulching in Agroecosystems

Plants, Soil & Environment

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Soil Section

Effect of Mulches on Mineral Fertilizer (N, P & K) Management and Fertilizer Use Efficiency



Amir Aziz, Noor-us-Saba, Mukkram Ali Tahir, Qura-Tul-Ain, Adeel Ahmad, Ameer Hamza, Humaira Ramzan, and Bilal Ahmad Khan

Abstract Global crop productions are limited due to limited water and nutrient availability. To enhance the availability of nutrients different fertilizers are applied to the soil. But due to extreme temperatures or irregularity in the moisture levels, the efficiency of these fertilizers become reduced. Soil mulching (organic or inorganic) reduces evaporation, control soil temperature and enhances nutrient use efficiency, thereby affects crop yield and production. This chapter highlighted different aspects of mulching including, ways mineral fertilizer loss, strategies to manage mineral fertilizer and fertilizer use efficiency. Additionally, this chapter highlighted the effect of mulch material on mineral fertilizer (N, P & K) management and fertilizer use efficiency. Ways of improving fertilizer use efficiency for some important fertilizers are also discussed in detail.

1 Introduction

Mulch word derived from the German word “molsch” means “easy to decay”. It is widely used since ancient times for vegetable production (Lightfoot, 1994). It is defined as on soil surface covered by the spreading of various material to minimizing the population of weed and soil moisture losses and to enhance the yield of the crop (Nalayini, 2007; Kader et al., 2019). Mulches improve soil infiltration, minimize

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water runoff, control weeds population and also control evapotranspiration. Mulching shows other important environmental effects like minimum nutrient losses, reduce soil compaction and soil erosion, improve soil physical condition and also affect the regulation of temperature and plant roots in soil (Lamont, 2005; Ngouajio & McGiffen, 2004).

To enhance crop productivity and save soil from environmental degradation mulching of field is an appropriate agronomic technique (Giller et al., 2009; Knowler & Bradshaw, 2007). The things that can be used for mulching include polythylene sheets, straw of wheat and barley, corn stems, stones, sand, pebbles, geotextiles of biological nature, vegetative remaining as well as trample stones (Mo et al., 2016; Prosdociami et al., 2016). There are several benefits of mulching, that's why the status of this technique in the agriculture sector is good. One of its topmost benefits is a decrease in evaporation which in turn improves water use efficiency as well as crop yield. (Awe et al., 2015; Jemai et al., 2013; Li et al., 2015). Secondly, the soil temperature is also maintained which is useful for better germination of seeds and in the initial stages of development also helps in the growth of roots (Zhang et al., 2015; Siczek et al., 2015). Its third benefit includes the change in the microbial biomass as well as soil fertility, which consequently improves soil health and crop productivity (Zhang et al., 2011; Balota et al., 2014; Qiu et al., 2014; An et al., 2015; Huo et al., 2017; Munoz et al., 2017). Fourthly, the organic C of soil is maintained by mulching and nutrient cycles are regulated, consequently, crop yield is increased (Bationo et al., 2007; Liu et al., 2009; Naab et al., 2015; Wang et al. 2016). The metabolism of soil is also improved as mulching improves the enzymatic activities of soil (Elfstrand et al., 2007). Weeds can also be controlled effectively by mulching (Campiglia et al., 2015; Jabran et al., 2015; Nawaz et al., 2017; Splawski et al., 2016). Moreover, in the rainy season mulches prevent soil from runoff and enhance the water penetration capacity (Adekalu et al., 2007; Jordan et al., 2010; Smets et al., 2008). It improves soil aggregation as well as the structure of the soil (Luna et al., 2016). In summers weeds and soil-borne pathogens can also be checked by using black polyethylene mulches. Amongst all the above-mentioned reimbursement of mulching the most vital is soil moisture conservation change in soil temperature (Bu et al., 2013; Li et al., 2004; Montenegro et al., 2013; Zhu et al., 2015). On the other hand, the factors that affect the mulches include the time of mulching, duration of mulching; the material used for mulching, tillage practices and either the mulch is applied in furrows or ridges (Edwards et al., 2000; Li et al., 2004).

2 Mineral Fertilizers and Problems Occurring with Mineral Fertilizers

Mineral fertilizer is materials either manufactured or natural, containing nutrients that are essential for plant growth and development. Mostly mineral fertilizer term is used as synthetic, artificial or chemical fertilizer. Nitrogen, phosphorus and potassium

these three nutrients that have to be applied in large quantities to plants. Sulphur, magnesium and calcium are also required in considerable amounts. All these nutrients are major constituents of plant components such as proteins, chlorophyll, nucleic acid etc. All these components are essential for some process like enzyme action, maintenance of internal pressure and energy transfer. Almost seven nutrients are required to plants in small quantities are called micronutrients. The deficiency of any one nutrient can compromise plant growth and development. The relationship is very strong between fertilizer consumption level and agricultural productivity. After various inputs in agriculture after irrigation, contribute to an increase in agriculture production (Pilbeam, 1996).

Soil nutrients can failures to replenish in many countries. This problem can be solved through efficient and balanced use of plant nutrients and through improving the soil management practices. Some plant nutrients requirements can be fulfilled by the application of organic material that is available on the farm or in the community. This material is insufficient to replenish the nutrients of the plant removed from the soil. Plant obtained most of the nutrients from organic manure, soil reserves or recently added fertilizers. Plants uptake of nitrogen (50–70%), phosphate (15%) and potash (50–60%) nutrients during the application season (Pilbeam, 1996). Nitrogen uptake by plant and proportion in soil are varied widely in response to differences in evaporation and rainfall. Under control conditions, almost 50–70% applied nitrogen can be uptake by the plant and in practically, nitrogen losses can be much greater. Nitrogenous fertilizer can be lost by erosion, gaseous emission or leaching. All these processes can vary widely and depending on the environment and agricultural system. Similarly, denitrification and ammonium volatilization also varies and depends on form of N fertilizer used, agro-ecosystem, environmental condition and crop management. Sometime problems arise after the large application of nitrogen fertilizer like ammonium volatilization and denitrification in sugar cane, cotton and rice crop. Farmers are unconcerned about the excessive application of nitrogen fertilizer when economic situation is good, but environmental problems are arises. Many approaches are available now days to control the nitrogen losses by ammonium volatilization and denitrification (Peoples et al., 1995). By the application of mulch former can control the loss of nitrogen. On the other hand, by improving management practices reduced gaseous loss of nitrogen about 14 kg/ha (Matson et al., 1998). By the loss of phosphate and potash from soil system also decrease the crop yield and which represent financial loss to farmer. It may also cause environmental risk, in that soil lost by wind and water erosion to stream, lakes and rivers. Phosphate has both effects; direct and indirect. Increase phosphate availability show positive effect on quality and quantity of crop. Through indirect interaction phosphate increases crop production by adding nitrogen and potassium and also show positive effect on soil organic matter, biological nitrogen fixation, soil erosion control, water holding capacity and other physio-chemical properties of soil (Baanante, 1998).

3 Reasons for Low Fertilizer Use Efficiencies

Soil pH is the major factor of nutrient use efficiency in the soil system. This is for two reasons. Firstly, extremes of soil pH can decrease crop growth and development. For example, at low pH, the toxicity of manganese and aluminium can restrict the crop growth and yield and at high pH of soil deficiencies of micronutrients limits the growth and yield. Secondly, in the soil system, pH markedly affects the chemistry of phosphorus and ultimately its effect on phosphorus adsorption by the interaction that precipitation of phosphorous into solid forms in the soil system (Willett & Higgins, 1978).

The amount and type of clay present in the soil system are strongly affected nutrients availability and phosphorous adsorption. Soils having high clay content retain more nutrients (especially phosphorous) strongly. In high sandy soil, nutrients (P) do not retain and leaching from the soil system. Most phosphorous uptake by the plant from the soil system through the diffusion process (higher concentration in soil solution and low concentration at root surface). On the other hand, drought can severely decrease phosphorous use efficiency. Flooding of soil can also reduce the oxygen status in the soil system and ultimately reduced the nutrient use efficiency by plants (Willett & Higgins, 1978).

4 Ways to Improve Fertilizer Use Efficiencies

The soils with elevated Phosphorus retaining capacity due to adsorption reactions, placing the Phosphorus as band placement is the safest managing practice for soluble Phosphorus fertilizers as this lessens the extent of soil fertilizer contact as well as restricts powerful adsorption. Additionally, broadcast Phosphorus is superlative for sparingly soluble fertilizers (Chien et al., 2009).

Phosphorus fertilizers including MAP, DAP and TSP have analogous Phosphorus use efficiency in many soils, provided there are no further confines to crop development (deficiency of nitrogen will favour MAP, DAP over TSP, or deficiency of calcium will favour TSP). Rock phosphates and struvite are less soluble which give an alkaline reaction in the soil that will usually be less efficient than soluble Phosphorus sources except for acidic soils, or soils susceptible to Phosphorus leaching. Soil acidification enhances the usage efficiency of Phosphorus acidifying fertilizers will have benefits over that alkaline in reaction. Of the various additives and microbial inoculants asserted to enhance usage efficiency of Phosphorus, not a bit have been shown up to date to regularly deliver substantial advantages (Chien et al., 2009).

5 Importance of Mulching

In the top 30 cm of soil, most of the water is available. So, upper soil areas are required to be remained moist to encourage root growth as well as to deliver sufficient water for the plant. Mulching performs a substantial role in conserving soil water. Additionally, mulches inhibit weeds and retain a narrow array of temperature in the soil. Therefore, soil structure, soil moisture as well as optimum fertilizer levels will improve onion production. Inorganic mulches (such as black or white polythene) or organic mulch are a logical expense and preserve soil moisture. Using residues of plants or synthetic materials as a mulch material is a well-recognized procedure for enhancing the effectiveness of several horticultural crops (Mukherjee et al., 2004).

Mulches can conserve soil moisture and reduce evaporation ultimately reducing the irrigation requirements. The mulch materials act as barriers against raindrops beating action and irrigation water which carry spores of diseases. These spores are attached to plant shoots and foliage. Mulches provide nutrition to many organisms (beneficial) which competes against pathogenic spores or inhibit the pathogens by releasing chemicals. In this way, mulching reduces the chances of disease occurring. Mulches also an important part of integrated pest management (IPM) (Chalker-Scott, 2007).

Heavy metals are very harmful to both humans as well as animal's health. Mulching material is a good source for the removal of these harmful metals from the soil system (Chalker-Scott, 2007). For the removal of heavy metals, leaves of pine, poplar and eucalyptus are mostly used (Salim & El-Halawa, 2002). In forest areas, compost and woodchips are used that convert copper metal into a form that is not/less toxic for plant growth and development (Kiikkila et al., 2002).

Mulches deal with different pathogens by decreasing the stress level on plants. Plants get resistant to weed attack. In this way, there will be no use of any type of herbicides and insecticides. Decline the use of these chemicals leads to favour of beneficial organisms in soil and environment and also non-use of these chemicals leads to favour of farmers in sense of no money is used to purchase such chemicals (Chalker-Scott, 2007).

Whenever people use fertilizer, mulches and synthetic chemicals, they estimate the benefits outcomes and cost from investment. Compare to synthetic material, mulches are not so costly in term of crop growth and soil health. By the use of mulches, there will be no cost of purchasing pesticide and other weeds control methods. For rehabilitation of damaged lands, we can use local wood debris to enhance crop growth and development and increase farmer income. Timber and peat harvest residues are locally available mulch material that is economical and enhance crop growth (Kader et al., 2019).

6 Importance of Mulching on Fertilizer Dynamics

Mulches enhance the nutrient status of soil, conserve soil moisture, control soil temperature, weeds control in crop, control erosion losses, and remove the residual effect of heavy metals, fertilizers and pesticide. On the other hand, organic mulch influences the properties of soil and also affect soil health and fertility. Mulch materials also increased the availability of organic carbon, potassium and phosphorus that enhance crop yield and growth. Mulch materials also affect soil pH, nutrient availability and soil salinity (Kar & Kumar, 2007).

6.1 Soil Fertility Improvement

The organic mulches show beneficial impacts on soil health in term of improving nutrient levels. However, material type, climate conditions and characteristics of soil determine the decrease, increase, or no effect on soil nutrients. The application of organic mulches is more beneficial. It is because organic mulches decomposed in the soil system and providing the plant nutrients (described in Fig. 1). Different organic mulches (straw, bark, green manure and wood chips) provide plant nutrients as compared to inorganic mulch materials (Ansari et al., 2001). Mulch materials containing high nitrogen content increase crop yield and production. On the other hand, mulches having low nitrogen content (straw, sawdust and bark) also increase plant nutrients and soil fertility (Chalker-Scott, 2007).

6.2 Lowering the Soil pH

A few mulches are acidifying the soil. However, there is no scientific evidence about soil acidification by the application of mulching. The bark of wood chips and some trees are the main source of acidification. Organic mulch soils are more acidic as compared to inorganic mulch or bare soil. In a nursery, the application of woody mulch can produce phenolic acid due to woody materials decomposition. However, in field conditions, there is a very acidifying effect by the application of woody materials. Some researchers found that, in acidic soil, there is no acidifying effect. But in alkali soil, organic mulch material shows a positive effect for lowering the soil pH (Chalker-Scott, 2007).

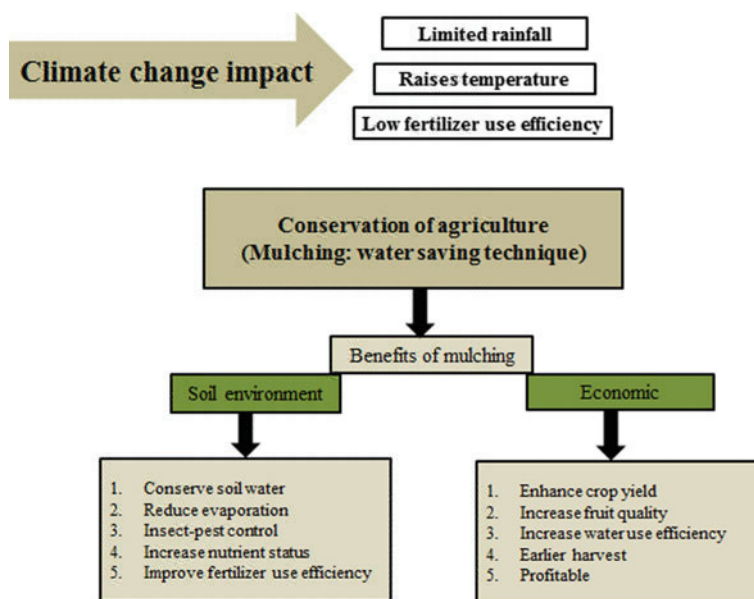


Fig. 1 Effect of mulching on fertilizer use efficiency

7 Mulching and Fertilizer Use Efficiencies

By the application of organic mulching, soil organic matter increased. Ultimately, nutrient availability increased and enhances the biological as well as physical properties of soil (Kader et al., 2019; Wei et al., 2009). Management practices (tillage, irrigation, straw mulching and fertilization) have a significant effect on soil enzymes and total soil organic matter (Ali et al., 2018; Lefèvre et al., 2014; Smith et al., 2011). Application of fertilizers (organic or inorganic), crop rotation and tillage practices improve the soil microorganisms and soil ecosystem. To check the nutrient availability, fertilization practices are an important indicator in soil and are linked with crop production and fertility of the soil. Soil enzymes activities are also increased by the added nitrogen and carbon into soil (Akhtar et al., 2018). Soil enzymes activities have also involved in the availability of nutrients and nutrient cycling. Long term organic mulches application increased soil organic matter and soil enzyme activities. Researchers found that by increasing soil temperature, enzymes sensitivity also increased (Bowles et al., 2014; Stone et al., 2012; Zhou et al., 2013). Atmospheric temperature increases due to global climate warming and ultimately negative impact on crop growth and development. So, a scientist had new innovative approaches for improving efficiency and yield of the crop with minimum impact on ecosystem and environment. For this innovation, direct seeding of wheat after the harvesting of rice and eliminated the burning of residue thus stabilized soil organic matter and reduced environmental pollution (Anand et al., 2016).

8 Conclusion and Remarks

Application of mulching can suppress weed population, conserve soil moisture by reducing evaporation and enhance nutrient status in soil. Different mulching materials significantly impact crop growth, yield and quantity. However, it can be concluded from the literature that, mulches are a good and cheap source to conserve soil moisture, reduce weed populations and control soil temperature. Therefore, in drought/water deficit conditions, the water requirement of the crop could be compensated by properly managed mulching strategies. Moreover, integrated use of mulch with partial rootzone drying is an efficient technique to enhance crop yield and development. All type of mulches improves soil quality concerning crop growth and yield. Besides, mulching also improves fertilizer use efficiency by reducing their losses. Mulching not only creates a hindrance against the volatilization of fertilizers but also improves the moisture and nutrient status of the soil. Though mulching shows positive effects on yield, water use efficiency and nutrient use efficiency. In the future attention could be focused to manage mineral fertilizer (N, P & K) and nutrient use efficiency by using organic and inorganic mulches in combination, as organic mulches will enhance the organic matter of soil as well as nutrient use efficiency.

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Effects of Mulching on Soil Biota and Biological Indicators of Soil Quality



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Abstract The concept of soil health has gained importance recently, recognizing the soil as a living entity. In the recent scenario of urbanization and excessive land use, agricultural land is subjected to degradation and desertification. For sustainable agriculture production and ecological interactions, there is a dire need for management strategies to improve soil health and quality. Mulching is among the important conservation strategies to enhance soil health by improving soil biota, organic contents, and soil aggregation. In this chapter, we encompassed the different categories of living entities dwelling in soil and their key activities to enhance ecological relations of soil. Based on the literature study, mulches are proved to be very efficient in improving soil biota, soil moisture retention, maintaining the soil temperature, nutrient dynamics, decrease in severity of soil contaminants, suppression of weeds, and control in insects pests. The addition of mulch in the soil fluctuate a number of indicators of soil biota, which account for soil health. Species diversity, microbial biomass, soil respiration, organic content, and enzymatic respiration mainly determine quality status of soil biota, which are influenced by mulches. We have also given the overview of indices of species diversity, i.e., richness, evenness, and phylogenetic indices altered by the introduction of mulches in soil and thus modify the ratio of pests predators. Moreover, based on field conditions, crop and mulch type, and environment-specific application of mulch can become more productive for soil conservation, plant growth and soil biota.

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1 Introduction

1.1 Importance of Soil Biota for Soil Health

Soil biota acts as one indicator of soil health, enabling the soil to function as a living system in an ecosystem for sustainable productivity. Biological activity in the soil mainly occurs in the 30 cm top layer of soil (Serrano et al., 2009). This layer of soil comprises of less than 0.5% biological components and 10% of organic matter generally. Biological/Living components of soil are the soil organisms inhabiting and being decomposed in the soil, for example, protozoa, earthworms, microarthropods, enchytraeid, arthropods, termites, fungi, algae, bacteria, and soil flora (Roger-Estrade et al., 2010). Regardless of being small in size, soil biota acts as a key player in nutrient cycling and accelerate the decomposition process of organic residues. Many protozoans and insects dwelling in soil favour mechanical mixing, enhancing the physical structure while microbes largely contribute in nutrient dynamics in the soil. In simple words, the energy cycle in soil ecosystem is driven by microbes mediated decomposition of deceased plants parts, animals, and organic matter. Thus, these organic constituents are possibly converted into biomass or subjected to the mineralization process yielding CO₂, H₂O, mineral nitrogen, phosphorous etc. (Curtin et al., 2012). The mineralized nutrients are consumed by microbivores such as protozoa and nematodes (Bloem et al., 1997). Likewise, waste material and synthetic organic compounds transformation and degradation are also mediated by soil microbes (Stenberg, 1998).

1.2 Soil Biota Components

Soil is a big reservoir of living entities which are interacting in the diverse system for stabilized soil ecology. Soil components based upon the size (length and diameter) are categorized as macrofauna, mesofauna, and microfauna (Huera-Lucero et al., 2020).

Macrofauna, as their name, indicates a class of large-sized organisms with their diameter ranging from 2 to 20 cm. For example, earthworms, gastropods, isopods, myriapods, some araneidae, and the majority of insects. This category includes invertebrates mostly and is regarded as soil engineers in terms of mechanical manipulation of the soil (Cabrera et al., 2011). Other important members of this category include beetles, ants, snails, slugs, centipedes, millipedes, and, enchytraeid worms.

Intermediate sized organisms having body size between 1 and 2 mm is known as mesofauna. They are also known as microarthropods, belong to an invertebrate group. Their examples include nematodes, rotifers, tardigrades, small araneidae, pseudoscorpions, opiliones, enchytraeids, insect larvae, small isopods, and myriapods (Scheu et al., 2005). However, the key members of this class are mites and springtails, which constitute a large portion of this group. A square meter of land encompasses thousands of species belonging to this group. In the forest ecosystem,

they form the key reservoir and significantly affect the decomposition process (Mailard et al., 2019). They serve as a connecting bridge between macro fauna and micro fauna in the terrestrial ecosystems and act as key players among soil decomposers, and are mainly involved in nutrients fluxes and transformation of leaf litter and organic matter. Owing to a regulatory role in nutrients fluctuation and fluxes, they are regarded as webmaster of the ecosystem (Dervash et al., 2018). Organisms whose bodies size ranges between 20 and 200 μm come under the category of micro fauna. Major representatives of this class are protozoa, fungi, and bacteria. Nevertheless, the upper limit of this class also includes small mites, nematodes, rotifers, tardigrades, and copepod crustaceans. Like a predator, they feed on fungi and bacteria; their pathogenicity activity makes them a bio-control agent and also influences microbial biomass significantly in the soil.

2 Mulching and Soil Health Management

Mulch is defined as a covering of soil by the use of organic or inorganic material to improve plant performance by retaining soil moisture, maintaining soil temperature, reducing weed growth, inhibiting erosion, increasing fertility, and nutrient balance, and avoiding diseases and pests (Robichaud & Ashmun, 2013). Based on materials used for soil covering, mulches are generally classified into two broad types, i.e., inorganic and organic (Table 1). Nevertheless, usage of mulch is strictly dependent on its properties to affect soil characters, decomposing ability, resilience, and most importantly, their ease of access. Mulching increases the roughness of land surface, thereby reducing transportation, controlled flow of water that keeps the soil and water intact (Foltz & Wagenbrenner, 2010; Montenegro et al., 2013; Prats et al., 2016).

2.1 *Organic Mulch*

Plant and animal materials, ground-covers and compost are common organic mulches and are successfully being employed in agricultural farming (Montenegro et al., 2013). Organic mulches come from plants and animals sources and have reportedly been shown to improve soil health effectively (Adekalu et al., 2007; Teame et al., 2017). Organic mulches are further divided into living and non-living. Common examples of living mulches are *C. mucunoides* (leguminous), cowpea (field crop) and bracharia (grass) whereas common nonliving mulches include wheat, palm, and rice debris from the plant sources and cow, pig, poultry, horse, and goat faeces from the animal source are examples of nonliving mulches (Abrantes et al., 2018; Akhtar et al., 2018; Gholami et al., 2013). To nurture soil health and to promote sustainability, plant residues are used as mulches as well (Berglund et al., 2006).

Table 1 Describes the role of organic and inorganic mulches on soil moisture and temperature, indirectly affecting soil biota and eventually on crop yield

Mulch type	Crop	Year of cultivation	Impact on soil and biota	Impact on crop yield	Reference
<i>Organic</i>					
Rice straw mulch	Groundnut	2000–2001	Improved the soil temperature and water holding capacity of soil	Improved the crop yield by 28.73%	Ramakrishna et al. (2006)
Maize straw	Soybean	1990	Improved the soil respiration and microbial biomass by 52 and 26% respectively. Also enhanced the enzymatic activity in soil	–	Rabary et al. (2008)
Wheat straw mulch	Maize	2005	Improved the soil organic matter and soil moisture content by 50.87 and 17% respectively and decreased the soil bulk density by 4.9%	Improved the plant height, biological yield, and grain yield by 5.1, 8.08, and 18.1% respectively	Pervaiz, Muhammad and Khuram (2009)
Bahia grass straw mulch	Sorghum	2006–2007	Significantly enhanced the cation exchange capacity, soil organic carbon, total nitrogen, and available phosphorous contents in soil		Obalum et al. (2011)

(continued)

Table 1 (continued)

Mulch type	Crop	Year of cultivation	Impact on soil and biota	Impact on crop yield	Reference
Wheat straw mulch	Soybean	2008	Minimized the soil compaction and significantly improved the soil bulk density and nodule formation in soil by 22.5 and 93.8% respectively	Significantly enhanced the protein content and yield of plant	Siczek and Lipiec (2011a)
Wheat straw mulch	Watermelon	2010	Improved the temperature and moisture % of soil	Enhanced the crop yield by 10.96%	Parmar et al. (2013)
Rice straw mulch	–	2012	Regulates the soil temperature and soil moisture and significantly minimized the soil erosion and runoff by 21 and 51%, respectively	–	Montenegro et al. (2013)
Rice straw mulch	Rice	2014–2015	Significantly improved the soil moisture, temperature and soil microbial carbon in soil	Improved the root and shoot biomass of plant and enhanced the crop yield by 40%	Dossou-Yovo et al. (2016)
<i>Inorganic</i>					
Saw-dust	Calla lily	1996	Improved the soil moisture and temperature	Significantly improved the tuber yield by 90%	Wright and Burge (2000)
Polythene plastic	Groundnut	2000–2001	Improved the soil temperature and water holding capacity of soil	Improved the crop yield by 40.87%	Ramakrishna et al. (2006)

(continued)

Table 1 (continued)

Mulch type	Crop	Year of cultivation	Impact on soil and biota	Impact on crop yield	Reference
Saw dust	Strawberry	2010	Improved the soil moisture contents and maintain the C:N ratio in soil	Enhanced the crop yield by 79%	Kumar and Dey, (2011)
Polythene plastic	Watermelon	2010	Improved the temperature and moisture % of soil	Enhanced the crop yield by 25.62%	Parmar et al. (2013)
Gravel-sand	Watermelon	2006–2008	Significantly decreased the soil evaporation and improves the soil temperature and water use efficiency	Enhanced the crop yield by 21.9%	Wang et al. (2011)
Polythene plastic	Watermelon	2015	Improved the soil temperature	Enhanced the crop yield by 25%	Maughan and Drost (2016)

2.2 *Inorganic Mulch*

Inorganic mulches are a cost-effective mean as a soil management strategy popular in low-income countries and are mostly used for persistent agriculture (Ngosong et al., 2016). Recently, the use of plastic mulch has gained hype due to its ability to reduce moisture loss, especially in drought-stricken areas (Li et al., 2004; Yu et al., 2018). Nevertheless, merit and demerits vary with types of mulch being used; for instance, it was reported that organic mulch positively impacts root systems and nodule formation while the negative effect of plastic mulch was seen (Dukare et al., 2017). It is desirable to understand the properties and their potential effect on soil flora and fauna before application at the farmer's level. Plastics, gravels, soils, and carpets are listed in inorganic mulches; their utility varies with purpose, i.e., from protecting soil to erosion, extreme weather, weed control, and moisture retention as well (Ingman et al., 2015). The area under plastic mulch cultivation has been exponentially stretched all over the world, considering water scarcity and their possible ability to cope with less water supply. China has stepped forward as the top most consumer of plastic mulch (Ingman et al., 2015). The use of plastic mulch offers an effective way to curtail water loss, also being an economic strategy for saving water (Table 1). The use of plastic mulch is accompanied by a number of protective roles, i.e., avoid soil erosion, suppress diseases, pests, and weed proliferation, save plants from heat, cold, flooding and drought with improvement in food quality and production (Espf et al., 2006). According to (Zhou et al., 2009), with the use of plastic mulch, production of maize, and yield was boosted, and it served as the best strategy to save water and to regulate the temperature in dry land areas. As a result of plastic mulch, water use efficiency was enhanced, which led to a loss in subsoil water, thereby increasing crop transpiration rate and increasing yield in relation to traditional water application methods. The use of plastic mulch and its intended benefits is dependent on several factors, including type and quality of mulch being used, the surface under coverage, weather conditions, soil type their, and interactive effects. Different colours of plastic mulch showed differential effect which is associated with water conditions and the intended objective for which they are being used, and it offers great challenge (Ashrafuzzaman et al., 2011; Ocharo, Korir & Gweyi-Onyango, 2017).

The impact of plastic mulch on soil biodiversity should ascertain to positively regulate the soil properties and to improve sustainable agriculture food production. For that reason, idiosyncratic responses are pieces of evidence that could support the proliferation of several disease and insect's suppression of others (Torres Bojórquez et al., 2017). It has reportedly been mentioned that plastic mulch supports the arthropod and omnivorous population and their species diversity and regulated the fungi and bacterial community (Addison et al., 2013; Farmer et al., 2017; Qin et al., 2017). Plastic mulch offers higher protection in summer squash against watermelon mosaic virus, and their use was beneficial to protect some cultivars against viruses (Boyhan et al., 2000; Walters, 2003). A number of studies noted no effect of plastic

mulch at all or decline in number and density of carabid beetle, springtails, earthworms, parasitic, and predatory organisms and the soil food-web structure (Addison et al., 2013; Stirling & Eden, 2008; Tuovinen et al., 2006).

The massive use of plastic films also includes impact environment, soil and a series of other effects affecting agriculture developments (Gao et al., 2019). The negative effect of a decline in the abundance of soil invertebrate, suppression of microbial growth, and bacterial composition was reported (Schirmel et al., 2018). Plastic mulch regulates biotic and abiotic factors, which lead to the extensive effect of soil microbe's activity and their performance. Hence, the use of plastic mulch, in the long run, offers great danger or drastic effect to soil biota of arable lands and leads to severer consequences to functional ecosystems (Steinmetz et al., 2016). Above all, it increases soil pollution due to their poor breakdown ability, which offers another threat to our environment (Liu et al., 2014; Vox et al., 2016; Wang et al., 2016). In addition, the uses of plastic mulch could cause a negative impact, which needs more in-depth and detailed experiments to be conducted in different regions and ecological zones of the world in order to get a good understanding of their use and its effect on soil microbes.

3 Mulches for Enhancing Biological Activities in Soil

Biological activities in soil are inevitable in order to sustain soil health, plant development and to transform nutrients into acceptable form. Fungi, bacteria, and algae constitute living flora of the soil, while living fauna is formed by protozoa, earthworms, termites, nematodes, arthropods, microarthropods, enchytraeid, etc. (Lal, 1988; Roger-Estrade et al., 2010). Bacteria, fungi and other micro life forms in the soil are involved in nutrient reservoir remodelling and their storage, intact soil particles, decomposition of organic matter, and perform a crucial role in nitrogen and carbon cycle and many other processes that are important to plants. Specifically, biological activities of soil microflora and fauna occur at the highest rate in the rhizosphere near the root zone of plants (Potthoff et al., 2005; Waid, 1999). Detail overview of the importance and metabolic activity was described in detail by Waid (1999).

Greater nutrient and organic matter content, better soil texture, and porosity as well infiltration is directly proportional to biological activities (Lal, 1988; Paz-Ferreiro & Fu, 2016). Among the factors that regulate biological activities include are fertilization, tillage operation, crop rotation, soil amendments, type, and characters of soil, soil composition and crop (Bonilla et al., 2012). Mulches enhance biological activities has become a globally known event (Lal, 1988).

An increase in microbial activity in soil is directly linked to enhanced activities of enzymes such as urease, dehydrogenase, urease, and β -glucosidase. Besides several other beneficial effects, the application of organic mulches stimulates and facilitates the soil flora and fauna effectively (Lal, 1988). In the wake of beneficial effects of soil mulches on soil health, it is suggested to leave the crop remains on the soil in order

to maintain physical properties of soil along with increase biological performance (Kahlon et al., 2013; Kashif et al., 2020).

Mulches with a low C/N ratio are regarded as high-quality mulches and are better in strengthening the diversity, growth and population of soil life forms. For example, it was reported that the earthworm population was affected by the use of mulch and its quality. Compared to low-quality mulch, the earthworm population was denser, with high-quality mulch having high C/N ratio application (Tian et al., 1997). The effect of mulch is more pronounced and noticeable in the topsoil layer just after the application of mulch (Yang et al., 2003).

Cultural practices are important to stimulate and facilitate the microorganism in the soils and are also beneficial for sustainable food production and reduction of the incidence of disease and pests (Abawi & Widmer, 2000). Organic mulches are preferably applied as a desire to encourage a favourable microbial community, which results in enzymatic stimulation, thus improving crop performance.

4 Indices of Soil Biota

4.1 Soil Respiration

Soil respiration is the flux of CO₂ released by soil organisms, i.e., plant roots, microorganisms, and soil animals (earthworms or nematodes), as a result of their biological activity (Fu et al., 2020). Recent studies highlighted that soil respiration is an indicator of the soil's ability to support plant growth and soil microbes (Wang et al., 2018). Soil respiration is an indication of the level of microbial development, plant debris, soil organic matter (SOM), and decomposition (Luo et al., 2001; Zheng et al., 2009). In addition, soil respiration in the soil is needed to preserve the soil quality, nutrients transformation (which may be utilized by plants), and as a result, improve the plant growth. Reduction in soil respiration rates means that the soil has little or no SOM or aerobic microbial activity (Raich & Tufekcioglu, 2000; Striegl & Wickland, 2001). It may also indicate that soil properties, i.e., aeration, available nitrogen, and temperature, which has a significant effect on soil respiration, are restricting the SOM decomposition and biological activity (Yinkun et al., 2013). Furthermore, nutrients are not absorbed from SOM to meet the nutrients requirement of plants and soil species due to a reduction in soil respiration (Ren et al., 2018). This has an effect on plant root respiration, which can contribute to plant death (Li et al., 2016). In flooded or saturated soils, incomplete mineralization of SOM occurs regularly, resulting in the formation of compounds such as alcohol and methane, which are classified as toxic to plant roots. Sulfur volatilization and denitrification are normal in such prevailing conditions leading to causes pollution of greenhouse gases and acid deposition (Fu et al., 2020; Li et al., 2016). Recent studies highlighted that agricultural practice such as the incorporation of organic mulches in soil tends to improve the SOM, which usually enhances soil respiration (Liu et al., 2016). It was noted

that combination of conventional tillage with decomposing inoculants and wheat (*Triticum aestivum* L.) straw as a mulch significantly enhanced the soil respiration in the hilly region of the South-West region of China by 1.01–5.58 $\mu\text{mol} (\text{m}^2 \text{s})^{-1}$ as compared to sole conventional tillage having no mulch and decomposing inoculants (Sun et al., 2019). In addition, it was also observed that mulching of straw significantly enhanced the soil respiration in soil from 13.7 to 68.7%. In another study (Zhang et al., 2015a, 2015b) reported that soil respiration was significantly improved by the addition of mulches in soil, i.e., 4089 $\mu\text{mol} (\text{m}^2 \text{s})^{-1}$ as compared to soil having no mulches (806.78 $\mu\text{mol} (\text{m}^2 \text{s})^{-1}$). The incorporation of organic straw as mulch generally expected to influence the release of CO_2 from the soil (Shaohui & Jingyu, 1997). In the dryland region of the Loess Plateau, it was observed that the utilization of straw mulching as an amendment significantly enhanced the soil respiration of winter wheat farmland (Guan et al., 2011). In another study (Zhang et al., 2005) observed that the rate of soil respiration tends to improve significantly with the increase in the decomposition rate of straw in the farmland. In a recent study, it was also observed the application of straw as mulch enhanced the soil respiration at the early phase of incubation and then decreased gradually during the later phase of incubation (Fu et al., 2020). Furthermore, fast and rapid microbial community proliferation may have resulted in the allocation of more substrates to their proliferation and development than to respiration, trends in lowering the soil respiration (Lee et al., 2012). Soil amended with straw mulches has a higher rate of soil respiration due to a higher concentration of SOC and organic carbon (Wang et al., 2018). Organic mulches, i.e., rhizodeposition, plant litter, and straw, serves as a substrate for soil microbial population to mineralize into CO_2 (Whitaker et al., 2014). Hence it was concluded that soil microbial population composition was not the only significant determinant of soil respiration, and SOC and potential carbon mineralization played a prominent role in deciding the variation of soil respiration (Zhang et al., 2005). However, in certain studies, it was noted that soil respiration rate under mulching and conventional tillage practices failed to achieve a consensus due to variation in climate, soil, and cropping pattern (Guan et al., 2011), which also highlighted that further deep analysis based research needs to be done to explore the potential effects of mulches on soil respiration with respect to topography, soil, climate, and cropping patterns.

4.2 Enzymatic Activity

Soil enzymes catalyze the decomposition of plant residues; play a vital role in nutrients cycling and the release of plant-available nutrients (Siczek & Lipiec, 2011a; Burns et al., 2013; Jabran, 2019). The materials on which soil enzymes act are known as substrate, i.e., plant litter and straw (Acosta-Martinez et al., 1999; Downer et al., 2001). Living and dead microbes, plant roots, and residues and soil organisms are all sources of soil enzymes (Akhtar et al., 2018). Enzymes that have been stabilized in the soil matrix aggregate or form complexes with organic matter (humus),

clay, and humus-clay complexes but are no longer connected to viable cells (Rabary et al., 2008; Richter et al., 2011). Enzymatic activities in soil are affected due to variation in soil temperature and pH (Pavan Fernandes et al., 2005). For the recycling of macro-compounds, i.e., pectin, chitin, hemicelluloses, lignin, cellulose, etc., microbial enzymatic activity is needed (Jabran, 2019). Some enzymes, i.e., glucosidases and hydrolases, are only active in the degradation of organic matter, while others are involved in nutrients mineralization, i.e., sulfates, phosphatases, ureases, and amidases (Akhtar et al., 2018). However, there is no clear evidence available that linked enzymatic activity to nutrients supply or crop production, with the exception of phosphatase activity (Burns et al., 2013). Since nutrients mineralization to plant-available forms is achieved with the aid of enzymatic activity, the correlation may be indirect (Wang et al., 2018). In recent years it was highlighted that application of mulches in soil significantly enhanced the enzymatic activities of soil. It was noted that the application of mulches significantly enhanced the beta-glucosidase, amidase, FDA hydrolysis, sulfatase, urease, and phosphatase that improves the nutrients cycling in soil (Zhang et al., 2019; Zheng et al., 2006). In another study, it was recorded that application of straw mulches in soil significantly improved the beta glucosidase, and phosphatase activity in soil by 59.48 and 65.68%, respectively, higher as compared to natural fallow land having no mulches (Rabary et al., 2008). Similarly, (Zhang et al., 2015a, 2015b) observed that the application of wheat straw as mulch in maize (*Zea mays* L.) field significantly improves the enzymatic activities of urease, invertase, protease, and dehydrogenase in soil. Likewise, (Siczek & Lipiec, 2011a) reported that the application of wheat straw as mulch in soybean (*Glycine max* L.) field improved the enzymatic activity of nitrogenase in soil. Application of maple (*Acer palmatum* L.) leaves as mulch in ryegrass (*Lolium perenne* L.) field improves the enzymatic activity of beta-glucosidase and dehydrogenase in soil (Acosta-Martinez et al., 1999; Hai-Ming et al., 2014) reported that incorporation of ryegrass as mulch in rice (*Oryza sativa* L.) field improves the enzymatic activities of phosphatase, arylsulfatase, arylamidase, and beta-glucosidase in soil. Correspondingly, (López et al., 2014) observed that the application of almond (*Prunus dulcis* L.) shells as mulch in avocado (*Persea americana* L.) field significantly enhanced the enzymatic activity of protease, dehydrogenase, and phosphomonoesterase in soil. Yet, to explore the potential effects of mulches on soil enzymatic activities, further deep research is required.

4.3 Organic Carbon and Total Nitrogen

Organic mulches decompose over time, adding organic matter, and nutrients to the soil that are becoming a part of the soil (Huang et al., 2008; Sainju et al., 2008). The key benefit of organic mulches is that they maximize the amount of soil organic carbon (SOC) in soil (Li et al., 2010; Monaco et al., 2008). Soil organic carbon and total nitrogen play a vital role in the soil fertility and quality, as it potentially affects the