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Improvement of crop and soil management practices through mulching for enhancement of soil fertility and environmental sustainability: A review

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KEYWORDS

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Soil nutrients

Soil moisture

Crop production

ABSTRACT

The logarithmic phase of the human population creates high food demand near the future throughout the world. On the flip side, improved crop production requires uninterrupted water irrigation. Therefore, sensible agricultural inputs are needed to overcome these concerns. New technology-based innovative agronomic research steps will boost the contemporary agriculture practices in developed and developing countries. Agricultural cropping systems could follow mulching practices as one of the best crop management practices for its water and nutrient management potential. It is primarily to accomplish healthy economic and environmental bonds. By covering the soil's surface with biodegradable resources such as organic and inorganic materials, mulching improves the physicochemical characteristics of the soil. This approach provides a favorable environment for the development of plant growth and fosters the activities of microbial communities. Additionally, it reduces the growth of weeds, manages erosion, gets rid of pesticide residue, and increases soil fertility. Mulching the soil surface has profound benefits in improving the soil moisture levels due to a reduced evaporation rate. This method is a practical agronomic entrance to reduce water scarcity and raise the chance of water conservation, notably in arid and semiarid regions. It can also boost crop security and production to meet the global food requirements. This review significantly focuses on the current influence and advantages of organic mulches for crop establishment in the agriculture sector, which can close the production gap between achievable and actual yield.

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1 Introduction

India is one of the agriculture-based countries that is grounded it's economy and environmental effect. It has a rich biome through a dryland farming-based food production system (Schimel 2010; Ghimire et al. 2017). In productive agro-management techniques, water is one of the governing limiting factors among various known factors. Furthermore, it represents a captain's role in active plant growth and productivity (Iqbal et al. 2019; Silva et al. 2019). It is the most desirable candidate to determine the essence of agriculture (Hanjra and Qureshi 2010).

Our current agriculture system has continuously faced limited water resources due to global warming and low irregular rainfall patterns, drastic changes in seasonal and climatic conditions, water limitation, and drought. These are the imperative factors that affect and maintain soil and aid in crop health and development (Kader et al. 2019). To cope with this dilemma, more resourceful and well-organized water usage in agriculture should be the top priority in Indian agronomy particularly, water deficit in drylands (arid and semi-arid regions), seasonally dry tropical forest (SDTF) areas, and rainfed agricultural lands (Barajas-Guzman et al. 2006). To combat this scourge, water conservation needs primary concern to promote crop production with drought management systems and sustain agricultural production (Barron et al. 2003; Zhu et al. 2015). In recent years, the reduced groundwater level from 0.5 m to 1.0 m has brought about truncated rainfall (Ranjan et al. 2017). However, water reaches the deeper soil horizon above 15% under mulched conditions (Zhang et al. 2007). A systematic water conservation practice is necessary to conserve natural resources, food development, food security, and solid farming practices. Recently, modern agricultural practices depend on low-cost inputs. Systemic removal of crop residues reduces the biomass in croplands. Consequently, soil fertility and soil organic carbon (SOC) exhausts. Mulching, mowing, and composting are economically valid soil inputs that could be an alternative to the management of agroecosystems (Uhlirova et al. 2005).

Various mulching innovations are currently being added to agricultural practices to boost crop production. But, it is still in the early stages of development. Mulching breakdowns severely limit the soil ecosystem's long-term vitality, which is hampered by many obstacles. Very little research information is available about the biochemical and molecular mechanisms and interactions of soil microbiota with mulch that need further examination. There exists inadequate exploration of soil physiochemical parameters before and after mulch treatments on the surface. Therefore, more research is required to enhance the sustainability and viability of the agriculture systems through various types of mulching. Continuous and dynamic efforts are required, to accomplish feasible agroelements of future green agriculture sustainability. It will be fascinating to explore attainable potentials for agrotherapeutics (Figure 1).

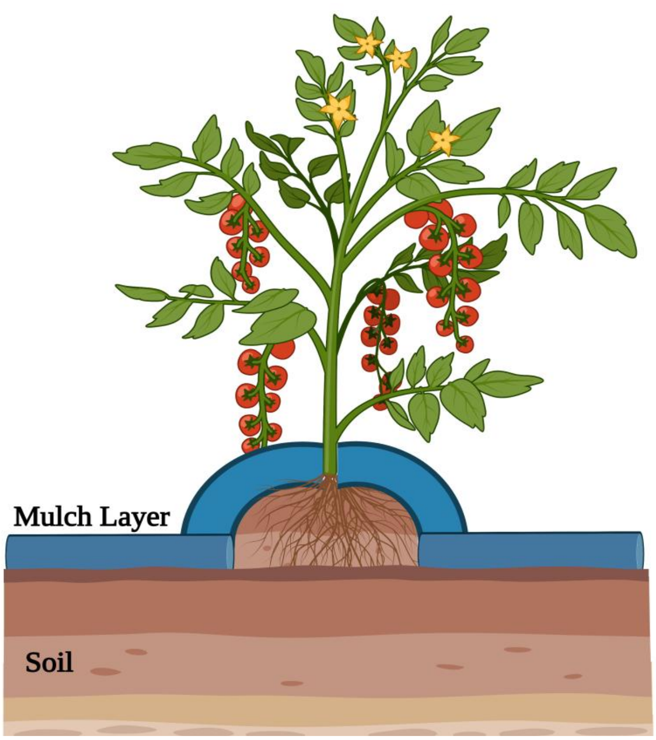

Figure 1 Diagrammatic representation of mulching for improved crop production

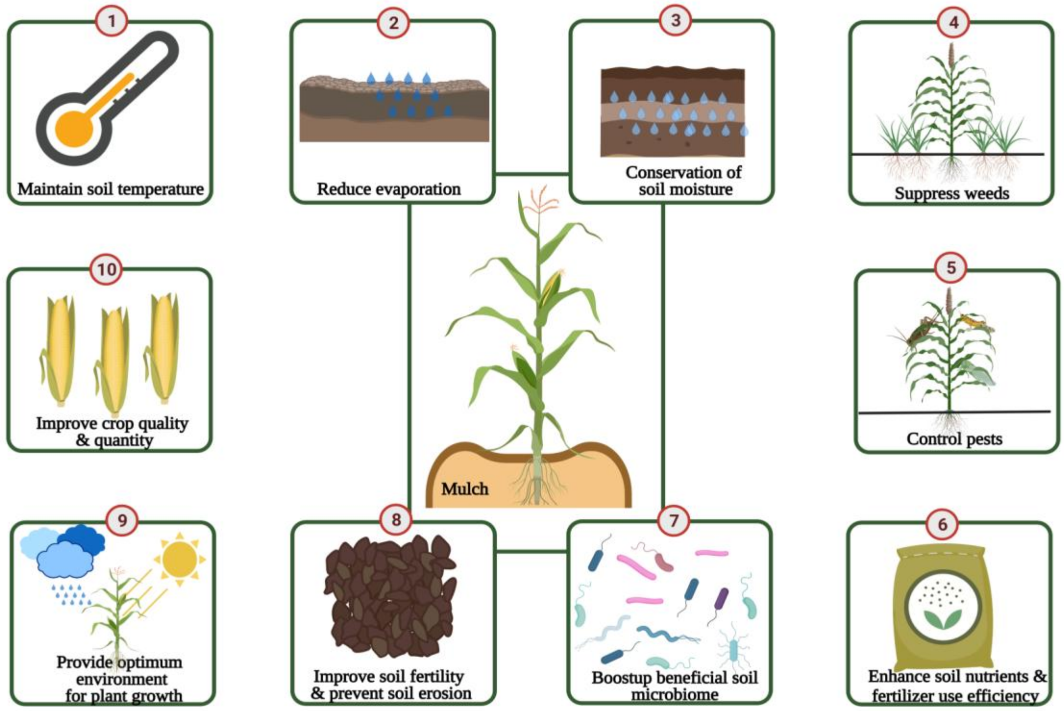

Figure 2 Beneficial spectrum of mulching in agriculture

2 Mulching for Contemporary Agriculture

In modern agriculture practices, mulching is one of the most important economic forces. It is an upward trend for effective water scarcity management through agronomic water conservation measures and enhanced rain-fed crop productivity with more benefits (World Bank 2002; Kader et al. 2019). Mulching refers to covering the soil, which acts as a physical barrier to crop productivity and soil health management. The term mulch means soft to decay. It is an agronomic practice of covering the soil surface with fresh or dry leaves or straw or plastic film, as displayed in figure 3. The positive effects of mulching primarily depend on the plant's response to water. The mulching practice provides essential nutrients, suppresses weed, maintains soil temperature, reduces evaporation, control pest, and enhances soil moisture (Figure 2) to address low crop production due to drought conditions (Patil et al. 2013). It also contends food demand for ever budding populations (Serrano-Ruiz et al. 2021).

3 Mulching and Microbiome

Various mulching practices have a tremendous impact on the soil microbiome like soil bacteria, fungi communities, and the ecosystem (Wu et al. 2022). It also enhances the soil microbial diversity and its functional properties, which interact with the plant rhizosphere region. In addition, it also promotes interrelations of soil microbiome, which improves soil quality (Wang et al. 2020). Its metabolic activity directly influences plant growth. Zhang et al. (2020) followed high throughput 16S rRNA and rDNA gene Illumina sequencing methods in tea plantation soil to assess the variations of the microbiome of plastic ethylene film mulch and peanut null mulch and reported the presence of top four bacterial phyla namely Proteobacteria, Actinobacteria, Acidobacteria, and Chloroflexi and three fungal phyla including Ascomycota, Mortierellomycota, and Basidiomycota. Lee et al. (2021) recently used five various types of mulching, including sawdust, green weed mat, and sawdust on top of the green weed mat. During the mulching process, soil changes the physical and chemical properties that drive microbial communities vary in their structure and metabolic activities. The soil microbial diversity varies according to the types of mulching methods followed. The covering of soil with organic mulches enriched the soil's microbial communities (Zhang et al. 2020).

4 Types of mulching

Various types of mulching followed in agriculture are surface and vertical mulching, mulching with pebble, straw, dust mulching with active organic materials, etc. Based on the utilization of materials, two types of mulches i.e. natural and synthetic are generally found (figure 3). Organic (natural/ biodegradable) mulch consists of organic materials, especially plant residues. The inorganic mulch is made of plastic-based materials (Kader et al. 2017). The agronomic performance profile of mulching is presented in table 1.

Table 1 Agronomic performance profile of mulching

Mulch Type	Beneficial crop	Beneficial Effects	Description	References
Plastic Mulching	*Capsicum frutescens* L., (Tabasco Pepper)	• Enhanced pepper production per unit area • Increased fruit dry mass percentage, water use efficiency, and potassium use efficiency in sandy loam soil	Mulching with drip irrigation	Chaves et al. 2021
Jatropha leaves Mulch	*Triticum* (Wheat (Wadan-17) (rainfed) and (Pirsabaq-2013) (irrigated))	• Preserved soil moisture content • Reduced water stress adverse effects and effectively maintain plant water status.	Mulching alone	Irshad et al. 2021
Transparent and black plastic film mulch	*Zea mays* L. (Spring Maize)	• Improved soil hydrothermal conditions • Enhanced early seedling emergence and silking • Boosted kernel weight and volume • Greater rate of photosynthesis • TM and BM improved grain yields (2019) at 28.1% and 15.1% and 24.6% and 21.1% (2020) respectively.	Mulching alone	Li et al. 2021
Plastic mulch	*Zea mays* L. (Spring Maize)	• Regulated soil hydrothermal traits • Maintained appropriate soil temperature and moisture content to solve the heat stress and water shortage impact	No-tillage with plastic re-mulching	Yin et al. 2021
Biodegradable mulch (BDM) (clear and black)	*Zea mays* L. (Spring Maize)	• Both mulches improved maize yield • Regulated soil temperature and root structure • Maize protein, N, P content, and fat were greater in black BDM.	Ridge-furrow pattern with mulching	Wang et al. 2021
Double mulch with *in-situ* MSM (Maize Stover Mulch) and WHP/RW (White Hoary Pea/ Ragweed)	*Zea mays* L. (Spring Maize)	• Improved soil moisture content and leaf related moisture content	Double mulching alone	Ngangom et al. 2020
Inter-row cornstalk mulch and black ground fabric mulch	*Malus* (Apple)	• Increased bacterial and fungal microbial communities and soil health	Mulching alone	Wang et al. 2020
Organic mulches including rice straw, sorghum straw, sesame straw, and Sudan grass	*Sesame indicum* L. (Sesamum)	• Showed major effect on the conservation of soil moisture content • Improve grain yield	Mulching alone	Teame et al. 2017
Plastic mulch	*Zea mays* L. (Spring Maize)	• Reduced soil evaporation, improved the soil moisture content and its availability • Regulated the soil temperature • Enhanced maize growth and yield	Mulching alone	Zhang et al. 2017
Plastic/ straw mulch	*Triticum* (Wheat) and *Zea mays* L. (Maize)	• Enhanced 60 % of the yield, WUE (yield per unit water) and NUE (yield per Unit N) • Improved yield of wheat at 20% and yield of maize at 60%	Mulching alone	Qin et al. 2015
Plastic and Straw Mulch	*Oryza sativa* (Rice)	• Boosted up the retention potential of the soil moisture • Improved rice water productivity, spikelet fertility, paddy yield, and quality	Mulching alone	Jabran et al. 2014
Cassava starch and poly (butylenes adipate-co-terephthalate)PBAT mulch	*Fragaria* (Strawberry)	Perked up properties of soil, hold soil moisture, magnifies water productivity Improved productivity	Mulching alone	Bilck et al. 2010
Red clover mulch	*Lycopersicon esculentum* (Tomato)	Reduced fruit cracking, improves loner roots	Mulching alone	Bender et al. 2008

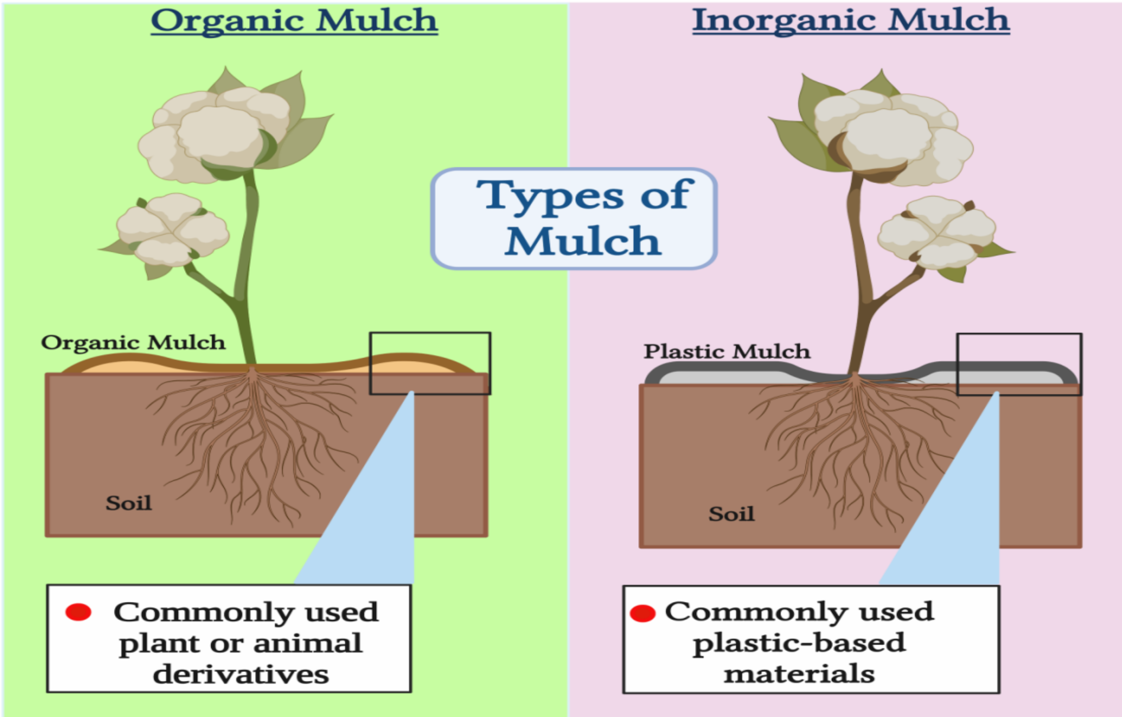

Figure 3 Types of mulch for enhanced crop yield

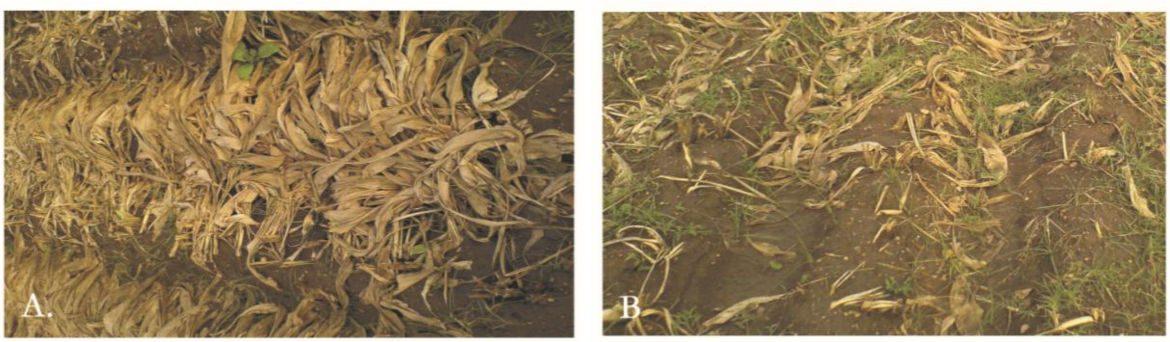

Figure 4 Organic mulched and non-mulched turmeric cultivation plots at Nambiyur, Erode District, Tamil Nadu (A- Mulched plot and B- non-mulched plot)

4.1 Organic Mulch

Organic mulch is obtainable organically and it undergoes microbial decomposition to release nutrients. For over 60 years, natural materials like leaves, sand, straw, silage, peanut hulls, dung, sawdust, woodchips, and animal manure yielded organic mulches. Sumathi (2010) used turmeric shoots as organic mulch and reported a significant growth in the turmeric (figure 4). Organic mulch could regulate and improve the physical, chemical, and biological properties of the soil (Xu et al. 2022). Mulching with organic materials is found to have many positive effects like soil erosion prevention, increased nutrient cycling, and enhanced biological activities (Yasar and Sahin 2021). It boosts soil health, facilitates minerals, and inhibits weed germination (Zhang et al. 2020). Besides, using organic mulch also reduced the soil temperature to 7°C (Oliveira et al. 2001). In addition, mulching with grass clipping has improved soil nitrogen and expanded the root system. Organic mulching is regarded as a key strategy in managing drought conditions because of the improved water retention capacity of the soil (Chen et al. 2015). The findings of Barajas-Guzma´n et al. (2006) reported that mulching is an effective technique to restore dry soil conditions and help reforestation by supporting plant growth and survival.

Organic mulch increases the sapling survival more than other mulches despite its shelf life of eight months, and it has attracted pests and insects to feed on them to decompose efficiently and needed frequent change. Organic mulch is highly beneficial than inorganic mulch based on its crop management potential (Ranjan et al. 2017). Mulching showed a positive impact and increased the soil infiltration rate. According to Molla et al. (2022), organic mulching increased the decomposition rate and intense soil nutrient concentration.

Biswas et al. (2015) used paddy straw as an affordable type of organic mulch and straw mulched conditions maintained 55% of soil moisture content. Straw materials mulching significantly improves the soil environment, plant growth, and vegetable crop yield as compared to non-mulched plants. The paddy straw mulch increased potato yield and their starch content. Further, even under reduced irrigation patterns also, paddy straw mulch produced a higher tomato yield. It stands for better water uptake, nutrient utilization, and soil-plant and water relationship. Advantages of using straw mulch are that they are eco-friendly, biodegradable, enhance soil water conservation, retained soil moisture, and increases plant growth development. Further decomposition of straw mulch released organic matter (SOM) into the soil and this type of soil can hold more water, rich in SOM encouraged the binding nature. In addition, the release of nutrients into the soil provided microbial communities with a substrate. Plant growth-promoting chemicals are secreted into the soil by microbial communities that are advantageous to humans to enhance plant growth. In comparison to straw mulch, soil water evaporation was slower under plastic mulch. It is viewed as a flaw in straw mulch (Biswas et al. 2015).

In the top soil layer, rice straw mulching has reduced water use by 30% more than in non-mulching settings (Chaudhary et al. 2004; Teame et al. 2017). None of the mulched crops exhibited signs of water stress, such as leaf rolling and wilting. It showed how mulch promoted nutrient delivery, lessened environmental stress, and boosted phosphorus availability to promote plant growth and development (Sardans and Penuelas 2004).

Use of wheat residue @ 6730kg/ ha increases the average moisture storage capacity up to 1.5m depth as compared to control and increases the 7–13% of root biomass of maize as compared to the non-straw mulched soils. Mulching with maize straw has minimal impact on SOC. At first, straw addition slightly raised the total SOC concentration by 2-3%. Over the years, increased SOC concentration is seen compared to non-straw incorporation (Wang et al. 2016). The grass is also used as a popular mulching material. Newly introduced grasses nourish the soil by supplying nitrogen sources into the soil. Under rainfed conditions, to avoid further root development by grass, dried grass materials are suggested (Patil et al. 2013). According to earlier studies, soil with grass mulch has high soil moisture content up to a depth of 60 cm (Teame et al. 2017) and reduced the loss of soil water due to evaporation by 35-50% (Hatfield et al. 2001). Mulching also helps in suppressing weeds because better rhizo-deposits of the rhizosphere contribute to soil fertility development and moisture conservation (Yin et al. 2013). Mulching increased the yield by producing increased fertilized cob number, seed weight, and more seeds (Niu et al. 2004; Ren et al. 2009). It has reduced irrigation frequency by slowing it down and less water usage (Rui et al. 2020). Mulching with drip irrigation is a good choice for water management practice to improve crop yield (Biswas et al. 2015). Crops use water and nutrients more effectively when the root zone of the soil has high soil moisture (Surya et al. 2000). Thick sheets of newspaper applied as mulch is simple and effective in weed control. Sawdust and bark clippings could be a great source of mulch materials. It is not employed widely because of its poor nutrient and less availability. Additionally, there exist specific restrictions when using organic materials such as mulch. The drawback of organic mulch is making the soil too moist, restricting oxygen entry near the rhizosphere, and encouraging the soil micro-communities to finally damage the plants.

4.1.1 Significant Effects of organic mulch

Soil water evaporation reduces the water use efficiency of crop plants. Agricultural production costs fall, when water use efficiency rises. Organic mulching practice reduces the water limitation by decreasing the soil temperature and soil water evaporation (Chai et al. 2014). Mulching also balances water and energy, buffering action against erosion by water and wind, and recycles soil nutrients to provide food and habitat for soil microflora. Crop residues used for mulching also help to alter microclimate, soil moisture, temperature patterns, etc. It increases soil moisture by modifying the soil water retention capacity. Mulching alters soil organic carbon levels (SOC) because plant-based residues are microbially decomposed (Liu et al. 2015). Indirectly, crop residues alter soil mechanisms based on their microclimate changing pattern, moisture in the soil and soil temperature regimes, water and solute transportation, and soil erosional principle. Mulching with organic materials makes weed control easier and improves soil nutrients. Finally, it promotes the development and production of microorganisms. In contrast, mulching the crop restricts the entry of light or a particular wavelength of light that supports weed growth (Ossomi et al. 2001). As a result of mulching, less soil water evaporated and the soil's moisture was consistently preserved. Retaining soil moisture causes the soil particles to stick together and maintain their close packing. When soil runoff gets reduced, soil erosion is prevented (Haribowo et al. 2021). Due to nutrient cycling, the process of mulching the soil probably improves the soil's nutrient status. The improvement of soil nutrient status promotes agricultural output and soil fertility (Sumathi et al. 2021). Even under rain-fed conditions, mulching boosts the crop yield by 50-60% over non-mulched conditions. Studies conducted by Tiquia et al. (2002)

demonstrated that mulching enhanced the SOM and P content of the soil. Thus, mulching increases soil nutrient content by preventing nutrient loss (Haribowo et al. 2021). Farmers can produce high-quality food in big quantities because of this technology.

Paddy straw as mulch increases the total yield of mulberry leaves more than non-mulched plots. Straw mulching also enhanced the phytochemical components of vegetables like tomatoes, cucumbers, melons, and eggplants. The tomato and okra plants with straw mulch have a higher yield as compared to the control plant. It was established that mulching has a considerable impact on both the quality and quantity of crops. Potato crops get benefited from paddy straw mulching because it raises yield and protects from weeds (Sureshkumar et al. 2021).

4.2 Inorganic mulch

Synthetic mulches are artificial and non-degradable. In the most recent update, mulching using synthetic materials, specifically plastic, has developed into an effective and cutting-edge integrated sophisticated technique in contemporary field agricultural output. It can increase soil moisture, eradicate pests, and treat plant diseases (Zhang et al. 2020).

4.2.1 Plasticulture Technology

Plasticulture is the practice of using plastics in agriculture (plasticization of agriculture). It is generally recommended to reduce water use and increase crop output, particularly in dryland farming (Kasirajan and Ngouajio 2012). In the 1950s and 1960s, plastic films were introduced to agriculture for both research and industrial vegetable production (Hussain and Hamid 2003; Lamont 2004).

Recently, plastic mulches are used worldwide, especially in developed countries, to produce and protect crops against modified weather, insects, weeds, and birds. Every year, the use of approximately 1 million tons of plastic film mulch has increased food productivity worldwide (Yu et al. 2018). In China, it is 40% to conserve water, which increases 53% of crop yield and conserved water by 24-26%. Globally, China is one of the maximum consumers of plastic mulch. It is regarded as the third agricultural revolution in Chinese history (Ingman et al. 2015). It is a cost-effective practice to improve soil temperature, reduce soil evaporation, and employ early harvest (Zhang et al. 2017).

4.2.1.1 Significant Effects of plastic mulch

Plastic mulch directly influences the underground water resources that provide the most favorable environment for plant growth and development. Furthermore, the aids of these mulching materials improved food production with increased quality and quantity (Ramakrishna et al. 2006). Mulch materials act as a soil insulating factor by delivering a buffer system from cold and hot temperatures, which provide decisive activity in creating fine fettle landscapes (Kader et al. 2019). Sizably reduce irrigation demand with conserve water economy. Plastic mulch functions as a barrier to maintain moisture and does not allow any moisture loss from the upper layer of the soil. It condenses on the lower surface of the mulch and returns as droplets were preserved for a long duration and conserve soil moisture at a stable level (Kader et al. 2019). The functioning of water stabilization in the rhizosphere area safeguards roots from excess rainwater impairment. Salinity is considered another serious concern affecting the crops in many countries. High saltwater contents are reduced greatly by water stabilization capacity during the mulching process. Its extended functions include plant uptake, transpiration, percolation into the soil and the crop even losses in water delivery (Ingman et al. 2015). It maintains soil water stress, the major limiting factor in plant growth maintenance and yield. It is one of the effective boosters for maintaining soil temperature and can induce an early crop yield. Besides, it can reduce nitrogen leaching or adds nitrogen to the soil (Frédéric et al. 2009). Soil bulk density and soil compactness was not affected by plastic mulch. The formation of soil aggregates also improved under the influence of soil moisture (Lalitha et al. 2010). The certainty of continuous fertilizer and biocontrol agent’s delivery and utilization in the root zone prevent water-soil nutrient-related diseases (Biswas et al. 2022).

The remarkable characteristics of plastic mulch such as reflectivity, transmittance, absorptivity, and solar radiation interaction (Lamont 2005) are the reason for increased temperature in the root zone area of soil. A mechanism that changes the soil's energy balance directly affects the microclimate. However, it is useful for cold climates, which induce and encourage faster germination, plant development, and productivity. Increased soil temperature directly influences nutrient availability, and efficient uptake of nutrients; enhances the activity of beneficial soil microbes. It also induces the soil, root, and air temperature (Tarara 2000; Rangarajan and Ingall 2001; Ruiz et al. 2002). Kwabiah (2004) recorded that under plastic mulching conditions air temperature raised to 11˚C than barren plots. Maintaining soil temperature at the top 20 to 30 cm of the soil profile is another important function of mulching, which promotes root and plant development. Due to changes in surface radiation and minimization in soil water loss, the plastic mulch has an impact on the microclimate inside and around the plant (Tarara 2000). Plastic mulch is crucial for impermeable gaseous flow. It acts as the grander barrier for the fumigants and solarization process along with the pest control mechanism (Chalker-Scoot 2007). Waterer (2010) reported that the characteristic clear mulches increase soil temperature, especially in warm-season vegetable crops grown in temperate climates. Plants are protected by the plastic film from a variety of environmental elements, including soil, water, wind, and hail damage. It operates for a prolonged period of 2-3 crop seasons (Kader et al. 2019) as it does not undergo decomposition rapidly and frequent replacement becomes unnecessary.

Some of the plastic mulch serves as a reservoir for methyl bromide, a potential fumigant, and ozone-depleting substance (Lalitha et al. 2010). The application of Low water uses efficiencies (WUEs) technology to help some plastic mulches to operate as a barrier and retains methyl bromide. It has led to desired results in productivity and profitability by airproof to prevent moisture and thermal proof to maintain the temperature at night. It provides better coverage than organic mulch as it is lightweight and easy to handle (Haapala et al. 2014). The agrometeorology of plant development and the health of the soil are both maintained by plastic mulch but it has negative effects on pollutants and plant pathogens (Kader et al. 2019).

4.2.1.2 Effect of plastic mulch in the field studies

Much of the existing research spectrum has enormously discussed the positive role of plastic mulch in the research area. Plastic mulch ominously enhanced vegetable production in the last decades worldwide, particularly, in tomato, brinjal, pepper, watermelon, musk melon, cucumber, squash, broccoli, etc. The same profound effects are observed in the crops namely corn, cotton, sugarcane, rice, and watermelon (Figure 5) (Bogiani et al. 2008; Lee et al. 2021). A white revolution was provoked by the rising production of peanuts (*Arachis hypogaea*) in China. The number of pods produced was reduced in black color plastic mulch are higher than the no mulching or straw mulching conditions (Ghosh et al. 2006). Twenty seedlings of three species belonging to Lonchocarpus ericarinalis Micheli (Leguminosae), Caesalpinia enostachys Benth (Leguminosae), and Ipomea wolcottiana Rose (Convolvulaceae) were subjected to experimental testing to assess the effects of plastic mulching under field conditions (Barajas-Guzman et al. 2006). According to their research, plastic mulches outperform other mulches in terms of soil volumetric water content (SVWC) and seedling survival rate. Plastic mulch did not affect the soil's pH, total N, total NH3, or total P organic content. The performance and production of tomatoes and cabbage were improved by the polythene mulch (Branco et al. 2010; Campagnol et al. 2014; Elsayed- Farag et al. 2018).

The Aliyarnagar Research Station reported that the plastic mulching increased the cotton crop productivity due to effective water conservation, and reduced weed growth than control of the cotton plant. The Tamil Nadu Agricultural University (TNAU) also reported that plastic mulching as a water economizing technology increased the height of the plant and the length of the root in red gram and castor crops under semi-arid conditions.

Yaghi et al. (2013) investigated the relationship between maturity time and cucumber (*Cucumus sativus* L.) production using plastic mulch and drip irrigation and enhanced the production rate twofold than the control. Using plastic mulching on vegetable crops such as ladies finger, tomato, and chili for three years produced higher yields, according to research done by the PDC in Coimbatore. Due to the improvement and alteration of soluble solid contents, total phenolics, flavonoids, and anthocyanins, reflection increased the output of Ontario wine grapes, plums, and butter beans. In strawberry and carrot, other color mulches increase the levels of phenolic chemicals, beta carotene, and ascorbic acid (Antonious and Kasperbauer 2002; Coventry et al. 2003; Kasperbauer and Loughrin 2004; Kim et al. 2008). Currently, mulching is a part of integrated agriculture methods that benefit agriculture (Table 2).

Figure 5 Plastic mulched plot for the cultivation of watermelon at Sathyamangalam, Erode District, Tamil Nadu, India

Table 2 Ultimate Mulching for Integrated Agricultural Management

Mulch	Agro-active compound	Crop	Effects	Reference
Paddy straw mulch, maize stubbles, and sawdust mulch	*Rhizobium* Biofertilizer	Pea Plant *(Pisum sativum* L.)	• Mulch with biofertilizer interactions (*Rhizobium* @30g/ kg of seeds with sawdust 210 t/ ha) demonstrated a better response on crop growth and yield	Muhammad et al. 2013
Pine needle mulch and black polythene mulch	NPK and *Azotobacter* fertilizer	Tomato (Naveen 2000, Sun-7711, Solan lalima)	• Studies proved that the three factors such as biofertilizers, variety, and mulch interactions improved fruit yield (1037.33 q/ ha) and quality. This study has employed 75% NPK+ *Azotobacter* (1g/ plant) + PSB (1g/ plant), Sun-7711 and black polythene mulch (V2B2M2).	Singh et al. 2017
Paddy straw and sawdust mulching	*Azotobacter* and PSB biofertilizer	Cauliflower (*Brassica oleracea* var. *Botrytis* L.)	• The combined application of bio-mulching boosts up the growth parameters including plant height, plant spread, and leaf weight. • It also enhanced quality traits such as TSS and ascorbic acid. • It improved curd density, average curd weight, and average curd yield/ ha along with the B: C ratio (3.16: 1).	Singh and Singh 2019
Sun hemp (*Crotalaria juncea* L.) mulch	Organics and *Azotobacter chroococcum* biofertilizers	Mulberry (*Morus Alba* L.	• Combined operations regulated soil moisture and major nutrients, which improved the growth rate, production rate, and quality of mulberry leaves under water stress conditions.	Chakraborty et al. 2016
Black polythene mulch and rice straw mulch	*Azotobacter* and PSB biofertilizer	Garlic (*Allium sativum* L.)	• Mulching along with biofertilizer enhanced the plant height, leaf length, stem diameter, bulb polar diameter and weight, total soluble solids, yield, no. of leaves in the plant, maximum number of cloves per bulb, thickness of bulb neck, length of cloves, pseudo stem and equatorial diameter of the bulb.	Anjali 2021
Silver plastic, black plastic, and wheat straw mulch	Biopesticides includes Chloropyriphos, Cypermethrin, neem oil, and *Trichoderma*	Okra Jassids (*Amrasca biguttula biguttula)*	• It improved fruit yield, pod length and diameter, and plant health.	Dahal et al. 2020
Biodegradable mulch - poly (butylenes adipate-co-terephthalate/ polylactide (PBAT/ PLA)	Herbicide 2-methyl-4-cholorophenoxyacetic acid/poly (3-hydroxybutyrate-co-3-hydroxyvalerate) (MCPA-PHBV)	Fava bean (*Vicia faba*)	• The symbiotic effect of biodegradable mulch with herbicide effectively suppressed the broadleaf weed species and improved crop health and yield.	Khan et al. 2020
Slash mulch	Insecticide	Norway spruce (*Picea abies* L. Karst.)	• The combined impact of insecticide-treated mulch improved crop survival rate. It has improved soil moisture and mineralization. • It enhanced the height, diameter, and volume of the seedlings.	Johansson et al. 2006
Biodegradable mulch - poly (butylenes adipate-co-terephthalate/ polylactide (PBAT/ PLA)	Biodegradable mulch conjugated with herbicide 2-methyl-4-cholorophenoxyacetic acid and poly (3-hydroxybutyrate-co-3-hydroxyvalerate) (MCPA) (MCPA-PHBV)	Fava bean (*Vicia faba)*	Biodegradable mulch with agro-active compound (MCPA-PHBV) controlled broadleaf weed species.	Kwiecien et al. 2018
Cover crop mulch	Organic herbicides (capric/caprylic acid, corn gluten meal, and herbicide-free)	Vegetable crops	Reduced weed pressure and need for tillage.	Lewis et al. 2020

5 Factors involved in mulch water-saving system

The effectiveness of mulching for water conservation depends on several parameters, such as the type of material used, the seasons, nutritive value, tendency, and the rate of decomposition. The ability of plastic mulch in water conservation depends heavily on the flexibility and site-specificity of agronomic practices. The reproducibility of the plastic mulch for moisture management, when combined with drip irrigation technology, is based on the crop cultivated, the climate, ecological locations, soil type, installation procedures, holes for transplanting, the color and thickness of the plastic mulch, the cut perforations in the plastic film, the pattern of irrigation, etc. (Yaghi et al. 2013; Ingman et al. 2015). In developed countries, micro-irrigation technology is largely followed for plastic mulching. In farms with sparse rainfall, plastic mulching is used in conjunction with a raised bed system or ridge furrow system to collect rainwater (Gan et al. 2013; Li et al. 2017).

Plastic mulches are clear, thin sheets of plastic film with varying colors and thicknesses, and dimensions. The type of plastics is based on polymers and their intended purpose. Commonly acetate, polyethylene, polymeric substances, low-density polyethylene (LDPE), High-density polyethylene (HDPE), flexible polyvinyl chloride, and ethylene-vinyl acetate have been used (Kader et al. 2019). Generally, PVC is preferred because of its easy process, longwave radiation, more efficient permeability, increased durability and flexibility, and absence of odor and toxicity. Especially black PVC provides better weather and chemical resistance, weed control, and loss for many seasons than opaque white and translucent film. It raised and sustained the soil's temperature throughout the night.

When applied in rows in the field, it seals the upper layer of the soil. The plants are grown by cutting or making holes in the plastic. It is then installed using hand tools or a mechanical process (Ingman et al. 2015). LLDPE is exploited on an economic level (Kasirajan and Ngouajio 2012; Yuan et al. 2022). LLDPE is less than one-third the density of LDPE, flexible, and highly durable. The thinner layer is still very functional and appropriate. LDPE is widely utilized in the USA and has a strong puncture resistance with mechanical stretch applications. HDPE has excellent moisture and vapor barriers (Lamont 2005; Ngouajio et al. 2007). Furthermore, the evaporation rate was influenced by the type of mulch (Chakraborty and Sadhu 1994). Plastic mulch does not change the physical, chemical, and biological properties for short-term applications. However, after the cultivation or harvest, the plastic covers are not completely removed and remain attached to the soil for the long term interfering with ecosystem cycling (Ramos et al. 2015). Soil microbial communities change their structure, biochemical composition, and diversity (Sreejata et al. 2018). Such alterations occur by modification of microclimates primarily.

5.1 Mulch Colour

Mulch color exhibits varied optical and spectral characteristics according to the intensity of light radiation to the soil. However, it directly influences the soil and air temperature, and soil salinity by reducing upward movement and evaporation of water and canopy distribution of the plant. This process used black, silver, white, red, blue, and yellow (Kader et al. 2019). Commonly used plastic film is black due to the greatest absorbing and reradiating warming properties. It does not allow the penetration of sunlight into the soil. Hence, photosynthesis did not take place in the absence of sunlight as it directly controlled and suppressed the weeds. It is better in colder climates. It has better controllability on weed flora. It is widely used in sandy soil, saline water, and weed control in crop plants (Amare and Desta 2021).

Silver mulch acts as an insect repellent when the mulch is used in summer cropped land. Elsayed-Farag et al. (2018) reported that white mulch increased the yield of tomatoes more than black mulch. However, the opaque white film is better in warmer climates, with the golden color it attracts insects through insect controllability. Red mulch-induced aroma compounds and minimizes the early blight on tomatoes (Lamont 1999). The phenolic contents of carrots are induced when yellow and black mulch is used. Yellow and white mulches optimized beta carotene and ascorbic acid contents more than other color mulches. IRT (Infrared Transmitting) mulch is the recent technology used to control the weeds due to warming properties (Lamont 1999).

5.2 Thickness and width of the film

Recent research reported that the thickness of the plastic mulch indirectly affects crop yield. The water vapor flow and thermal conductivity of the heat transfer mechanism depend upon the thickness of the film, commonly used as a thin film. The thickness of the film determines the water vapor flow and thermal conductivity of the heat transfer mechanism and typically a thin film is used. Generally, the recommended thickness of plastic mulch is 15-20µm, which 15µm is an effective one. But the preferred thickness of organic mulch is 4-8cm and under this situation, faster growth and earlier harvesting were achieved as compared to organic mulch. Thick mulches are frequently used in weed control via solarization in orchards and plantations. The width depends on inter-row spacing. Generally, 1-1.5 width is adopted for different conditions. In the rainy seasons, perforations are made to prevent water stagnation in the plants to improve plant growth (Kader et al. 2019).

Conclusion and Future Prospective

This review provides greater clarity about the importance of mulching in the agricultural sector. It is a promising method in contemporary agriculture to improve the soil's physical, chemical, and biological properties. It is the most economical procedure followed to increase crop production and protection. Both organic and inorganic mulching showed deep physiochemical interactions and significant positive crop responses were reported. When compared with other mulches, plastic mulches are highly effective. The socioeconomic study of plastic mulch demonstrates that it could be implemented for another green revolution. Mulching creates a new rebellion path to develop modern agriculture with plastic culture with colossal future opportunities. Even for the restoration of deforested lands, mulching methods are highly preferred. The mulching process is used for the perfect functioning of the ecosystem, and the soil-water content retention. In a broader sense, our study highlights the necessity of assisting farmers in overcoming the obstacles of integrated weed management to lessen the requirement for soil cultivation and reduce damage to beneficial arthropods. To comprehend the genetic and metabolic connections of the mulched crop, however, and to address the context of climate change and environmental sustainability, more research credentials are required.

The beneficial and controversial information on using plastic mulches is well recorded. The use of plastic mulches is expected to increase at 5.6% per annum by 2030. As part of the benefits of plastic mulching, a detailed study on the persistence and degradation of plastic residues or microplastics by soil microbial communities is ultimately required. This brings an environmental concern. There is no doubt that future agriculture authorities rely on rapidly evolving mulching methods with the progress of ecotoxicological studies. Although the expansion of value-added farming through mulching is desired for the development of an eco-soil regulatory framework. Furtherly, the probe of soil and its floral productivity is also paraphrased for crop productivity. In the future, mulched agriculture will be a dominant platform for the developmental scaffolding of smart agriculture.

Author Contributions

MR and SCS wrote main manuscript text and prepared figures; RP and RKV prepared tables and reviewed the manuscript.

Ethics approval and consent to participate

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Conflict of Interest

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References

Amare, G., & Desta, B. (2021). Coloured plastic mulches: impact on soil properties and crop productivity. Chemical Biological Technologies in Agriculture, 8(4), 1-9. https://doi.org/10.1186/s40538-020-00201-8

Anjali, S. (2021). Impact of organic and inorganic fertilizers on growth, yield and economics of garlic (Allium sativum L.). Annals of Plant and Soil Research, 23, 477-480. 10.47815/apsr.2021.10106.

Antonious, G.F., & Kasperbauer, M.J. (2002). Color of light reflected to leaves modifies nutrient content of carrot roots. Crop Science, 42 (4), 1211–1216. https://doi.org/10.2135/cropsci2002.1211

Barajas Guzman, M. G., Campo, J., & Barradas, V.L. (2006). Soil water, nutrient availability and sapling survival under organic and polyethylene mulch in a seasonally dry tropical forest. Plant and Soil, 287(1), 347-357. https://doi.org/10.1007/s11104-006-9082-7.

Barron, J., Rockström, J., Gichuki, F., & Hatibu, N. (2003). Dry spell analysis and maize yields for two semi-arid locations in east Africa. Agricultural Forests Meteorology, 117(1-2), 23–37. https://doi.org/10.1016/S0168-1923(03)00037-6

Bender, I., Raudseping, M., & Vabrit, S. (2008). Effect of organic mulches on the growth of tomato plants and quality of fruits in organic cultivation. Proceedings of the International symposium on growing media. Acta Horticulturae, 779(1), 341-346. https://doi.org/10.17660/ActaHortic.2008.779.42

Biswas, S.K., Akanda, A.R., & Rahman, M.S. (2015). Hossain Effect of drip irrigation and mulching on yield, water-use efficiency and economics of tomato. Plant Soil Environment, 61(3), 97–102. https://doi.org/ 10.17221/804/2014-PSE.

Biswas, T., Bandyopadhyay, P.K., Nandi, R., Mukherjee, S., et al. (2022). Impact of mulching and nutrients on soil water balance and actual evapotranspiration of irrigated winter cabbage (Brassica oleracea var. capitata L.), Agricultural Water Management, 263, 107456. https://doi.org/10.1016/j.agwat.2022.107456

Bilck, A.P., Grossmann, M.V.E., Yamashita, F. (2010). Biodegradable mulch films for strawberry production. Polymer Testing, 29 (4), 471-476. https://doi.org/10.1016/j.polymertesting.2010.02.007

Bogiani, J.C., Anton, C. S., Seleguini, A. Faria Junior, M.J.A., & Seno, S. (2008). Tip pruning, plant density and plastic mulching in tomato yield in protected cultivation. Bragantia, 67(1), 145-151. https://doi.org/10.1590/S0006-87052008000100018

Branco R.B.F., Santos L.G.C., Goto, R., Ishimura, I., Schlickmann, S., & Chiarati, S. (2010). Successive organic cultivation of vegetable crops in two irrigation systems and two soil covers. Horticultura Brasileira, 28(1), 75-80. https://doi.org/10.1590/S0102-05362010000100014

Campagnol, R., Abrahao, C., Mello, S.C., Oviedi, V.R.S., & Minami, K. (2014). Impacts of irrigation levels and soil cover on tomato crop. Irrigation, 19(3), 345-357. https://doi.org/10.1590/S0102-05362010000100014

Chai, Q., Gan, Y., Turne, N.C., Zhang, R.Z., Yang, C., Niu, Y., & Siddique, K.H.M. (2014). Water-saving innovations in Chinese agriculture. Advances in Agronomy, 126, 149–201. https://doi.org/10.1016/B978-0-12-800132-5.00002-X

Chakraborty, B., Kundu, M., & Chattopadhyay, R.N. (2016). Organic farming with bio-mulching–a new paradigm for sustainable leaf yield and quality of mulberry (Morus Alba L.) under rainfed lateritic soil condition. International Conference on Inventions & Innovations for Sustainable Agriculture 2016, ICIISA. Agriculture and Agricultural Science Procedia, 11, 31-37. https://doi.org/10.1016/j.aaspro.2016.12.006

Chakraborty, R.C., & Sadhu, M.K. (1994). Effect of mulch type and color on growth and yield of tomato (Lycopersicon esculentum). Indian Journal of Agricultural Science, 64(9), 608–612. http://dx.doi.org/10.46609/IJAER.2020.v06i01.007.

Chalker-Scott, L. (2007). Impact of mulches on landscape plants and the environment- a review. Journal of Environmental Horticulture, 25(4), 239-249. https://doi.org/10.24266/0738-2898-25.4.239

Chaudhry, M.R., Aziz A.M., & Sidh, M. (2004). Mulching Impact on Moisture Conservation ─ Soil Properties and Plant Growth. Pakistan Journal of Water Research, 8(2),1-8.

Chaves, S.W.P., Coelho, R.D., Costa, J.D.O., & Tapparo, S. A. (2021). Vegetative and productive responses of tabasco pepper to fertigation and plastic mulching. Scientia Agricola, 79(5), 10. https://doi.org/10.1590/1678-992x-2021-0084

Chen, Y., Liu, T., Tian, X., Wang, X., Li, M., Wang, S., & Wang, X. (2015). Effects of plastic film combined with straw mulch on grain yield and water use efficiency of winter wheat in Loess Plateau. Field Crops Research, 172, 53-58. https://doi.org/10.1016/j.fcr.2014.11.016

Coventry, J.M., Fisher, K.H., Strommer, J.N., & Reynolds, A.G. (2003). Reflective mulch to enhance berry quality in Ontario wine grapes. VII International Symposium on Grapevine Physiology and Biotechnology. Acta Horticulture, 689, 95-102. http://dx.doi.org/10.17660/ActaHortic.2005.689.7

Dahal, B.R., Rijal, S., Poudel, N., Gautam, B., & Neupane, R. B. (2020). Influence of different bio-pesticides and mulching in management of Okra Jassids Amrasca biguttula biguttula (Hemiptera: Cicadellidae) in Chitwan district of Nepal. Cogent Food and Agriculture, 6(1), 1-9. http://dx.doi.org/10.1080/23311932.2020.1829271

Elsayed-Farag, S., Anciso, J., Marconi, C., Avila, C., Rodriguez, A., Badillo-Vargas, I. E. & Enciso, J. (2018). Appropriate planting dates and plastic mulch for increasing common tomato varieties yield in south texas. Agricultural Research, 13 (26), 1349-1357. http://dx.doi.org/10.5897/AJAR2018.13212

Frédéric, T., Katrine, A.S. & Philippe, S. (2009). Use of Perennial Legumes Living Mulches and Green Manures for the Fertilization of Organic Broccoli, International Journal of Vegetable Science, 15(2), 142-157. https://doi.org/10.1080/19315260802598896

Gan, Y., Siddique, K.H.M., Turner, N.C., Li, X.G., Niu, J.Y., Yang, C., Liu, L., & Chai, Q. (2013). Ridge-Furrow mulching systems – an innovative technique for boosting crop productivity in semiarid rain-fed environments. Advanced Agronomy, 118, 429-476. http://dx.doi.org/10.1016/B978-0-12-405942-9.00007-4

Ghimire, R., Lamichhane, S., Acharya, B.S., Bista, P., & Sainju, U.M. (2017). Tillage, crop residue and nutrient management effects on soil organic carbon in rice-based cropping systems: A review. Journal of Integrated Agriculture, 16(1), 1-15. https://doi.org/10.1016/S2095-3119(16)61337-0.

Ghosh, P.K., Devi, D., Bandyopadhyay, K.K., & Mohanty, M. (2006). Evaluation of straw and polythene mulch for enhancing productivity of irrigated summer groundnut, Field Crops Research, 99(2–3), 76-86. https://doi.org/10.1016/j.fcr.2006.03.004

Haapala, T., Palonen, P., Korpela, A., & Ahokas, J. (2014). Feasibility of paper mulches in crop production: A review. Agriculture and Food Science, 23 (1), 60–79. https://doi.org/10.23986/afsci.8542

Hanjra, M.A., & Qureshi, M.E. (2010). Global water crisis and future food security in an era of climate change. Food Policy, 35 (5), 365–377. https://doi.org/10.1016/j.foodpol.2010.05.006.

Haribowo, R., Asmaranto, R., & Kusuma, L.T.W.N. (2021). Effect of rice straw mulch on surface runoff and soil loss in agricultural land under simulated rainfall. IOP Conference Series: Earth and

Environmental Science, 930(1), 012007. https://doi.org/10.1088/1755-1315/930/1/012007

Hatfield, J. L., Sauer, T. J., & Prueger, J. H. (2001). Managing soils to achieve greater water use efficiency. Agronomy Journal, 93(2), 271–280. https://doi.org/10.2134/agronj2001.932271x

Hussain, I., & Hamid, H. (2003). Plastics in agriculture. In: A.L. Andrady (ed). Plastics and the environment (Pp.185–209). Wiley, Hoboken.

Ingman, M., Santelmann, M.V., & Tilt, B. (2015). Agricultural water conservation in china: plastic mulch and traditional irrigation. Ecosystem Health and Sustainability, 1(4), 1-11. https://doi.org/10.1890/EHS14-0018.1

Iqbal, R., Raza, M.A.S., Saleem, M.F., Khan, I.H., et al. (2019). Physiological and biochemical appraisal for mulching and partial rhizosphere drying of cotton. Journal of Arid Lands, 11 (5), 785-794. https://doi.org/10.1007/s40333-019-0014-9.

Irshad, M., Ullah, F., Fahad, S. Mehmood, S., et al. (2021). Evaluation of Jatropha curcas L. leaves mulching on wheat growth and biochemical attributes under water stress. BMC Plant Biology, 21(1), 303. https://doi.org/10.1186/s12870-021-03097-0

Jabran, K., Ullah, E., Hussain, M., Farooq, M., Zaman, U., Yaseen, M., & Chauhan, B.S. (2014). Mulching improves water productivity, yield and quality of fine rice under water-saving rice production systems. Journal of Agronomy and Crop Science, 201(5), 389-400. http://dx.doi.org/10.1111/jac.12099

Johansson, K., Orlander, G., & Nilsson, U. (2006). Effects of mulching and insecticides on establishment and growth of Norway spruce. Canadian Journal of Forest Research, 36(10), 2377-2385. http://dx.doi.org/10.1139/x06-121

Kader, M.A., Senge, M., Mojid, M.A., & Ito, K. (2017). Recent advances in mulching materials and methods for modifying soil environment. Soil Tillage Research, 168(5), 155-166. http://dx.doi.org/10.1016/j.still.2017.01.001

Kader, M.A., Singha, A., Begum, M.A., Jewel, A., Khan F.H., & Khan, N. (2019). Mulching as water-saving technique in dry land agriculture. Bulletin of the National Research Centre, 43, 147. https://doi.org/10.1186/s42269-019-0186-7.

Kasirajan, S., & Ngouajio, M. (2012). Polyethylene and biodegradeable mulches agricultural applications: A review. Agronomy Sustainable Development, 32(2), 501-529. http://dx.doi.org/10.1007%2Fs13593-011-0068-3

Kasperbauer, M.J., & Loughrin, J.H. (2004). Crop ecology, management and quality: butterbean seed yield, color, and protein content are affected by photomorphogenesis. Crop Science, 44(6), 2123–2126. http://dx.doi.org/10.2135/cropsci2004.2123

Khan, H., Kaur, S., Baldwin, T. C., Radecka, I., et al. (2020). Effective control against broadleaf weed species provided by biodegradable PBAT/PLA mulch film embedded with the Herbicide 2-Methyl-4-Chlorophenoxyacetic Acid (MCPA). ACS Sustainable Chemistry and Engineering, 8(13), 5360-5370. https://doi.org/10.1021/acssuschemeng.0c00991

Kim, E.J., Choi, D.G., & Jin, S.N. (2008). Effect of pre-harvest reflective mulch on growth and fruit of plum (Prunus domestica L.). XXVII International Horticultural Congress—IHC2006: International Symposium on Enhancing Economic and Environmental Sustainability of Fruit Production in a Global Economy. Acta Horticulturae, 772, 323-326. http://dx.doi.org/10.17660/ActaHortic.2008.772.54

Kwabiah, A.B. (2004). Growth and yield of sweet corn (Zea mays L.) cultivars in response to planting date and plastic mulch in a short season environment. Scientia Horiculturae, 102(2), 147–166. http://dx.doi.org/10.1016/j.scienta.2004.01.007

Kwiecien, I., Adamus, G., Jiang, G., Radecka, I., et al. (2018). Biodegradable PBAT/PLA blend with bioactive MCPA-PHBV conjugate suppresses weed growth. Biomacromolecules, 19(2), 511-520. http://dx.doi.org/10.1021/acs.biomac.7b01636

Lalitha, M., Thilagam, V.K., Balakrishnan, N., & Monsour, M. (2010). Effect of plastic mulch on soil properties and crop growth-A Review. Agricultural Reviews, 31 (2), 145-149. https://arccjournals.com/journal/agricultural-reviews/ARCC1349

Lamont, W. (2004). Plastic mulches. In: W. Lamont (ed) Production of vegetables, strawberries, and cut flowers using plasticulture. Natural Resource, Agriculture, and Engineering Service (NRAES-133), Ithaca. Pp. 65. https://hdl.handle.net/1813/69448

Lamont, W.J. (1999). Bulletin on vegetable production using plasticulture. Tapei City, Republic of China on Taiwan: Food and Fertilizer Centre. Pp. 1-9. https://www.fftc.org.tw/htmlarea_file/library/20110808093747/eb476.pdf

Lamont, W.J. (2005). Plastics: modifying the microclimate for the production of vegetable crops. Horticulture Technology, 15(3), 477–481. https://doi.org/10.21273/horttech.15.3.0477

Lee, J.G., Chae, H.G., Cho, S.R., Song, H.J., Kim, P.J., & Jeong, S.T. (2021). Impact of plastic film mulching on global warming in entire chemical and organic cropping systems: life cycle assessment. Journal of Cleaner Production, 308, 12, 7256. https://doi.org/10.1016/j.jclepro.2021.127256

Lewis, D.G., Cutulle, M.A., Schmidt-Jeffris, R.A., & Blubaugh, C.K. (2020). Better together? combining cover crop mulches, organic herbicides, and weed seed biological control in reduced-tillage Systems. Environmental Entomology, 49(4), 1327-1334. http://dx.doi.org/10.1093/ee/nvaa105

Li, C., Wang, Q., Wang, N., Luo, X., Li, Y., Zhang, T., Feng, H., & Dong, Q. (2021). Effects of different plastic film mulching on soil hydrothermal conditions and grain-filling process in an arid irrigation district. The Science of the Total Environment, 795, 148886. https://doi.org/10.1016/j.scitotenv.2021.148886

Li, C., Wang., C, Wen, X., Qin, X., et al. (2017). Ridge-furrow with plastic film mulching practice improves maize productivity and resource use efficiency under the wheat-maize double-cropping system in dry semi-humid areas. Field Crops Research, 203, 201-211. http://dx.doi.org/10.1016/j.fcr.2016.12.029

Liu, L., Hu, C., Yang, P., Ju, Z., Olesen, J.E., & Tang, J. (2015). Effects of experimental warming and nitrogen addition on soil respiration and CH4 fluxes from crop rotations of winter wheat–soybean/fallow. Agricultural Forests Meteorology, 207(1), 38–47. http://dx.doi.org/10.1016/j.agrformet.2015.03.013

Molla, A., Desta, G., Molla, G. A., Desta, G., & Dananto, M. (2022). Soil management and crop practice effect on soil water infiltration and soil water storage in the humid lowlands of Beles Sub-Basin, Ethiopia Getnet Soil Management and Crop Practice Effect on Soil Water Infiltration and Soil Water Storage in the Humid L. Hydrology, 10(1), 1–11. https://doi.org/10.11648/j.hyd.20221001.11

Muhammad, S., Israr, H., Rab, A., Jan, I., Fazal, I.W., Shah, T., & Khan, I. (2013). Influence of organic mulches on growth and yield components of pea's cultivars. Greener Journal of Agricultural Sciences. 3(8), 652-657. http://dx.doi.org/10.15580/GJAS.2013.3.122912351

Ngangom, B., Das A., Lal, R., Idapuganti, R.G., et al. (2020). Double mulching improves soil properties and productivity of maize-based cropping system in eastern Indian Himalayas. International Soil and Water Conservation Research, 8(3), 308-320. http://dx.doi.org/10.1016/j.iswcr.2020.07.001

Ngouajio, M., Goldy, R., Zandstra, B., & Warncke, D. (2007). Plasticulture for Michigan Vegetable Production. Extension Bulletin E-2980 January 2007. Michigan State University, East Lansing, pp 20. https://archive.lib.msu.edu/DMC/extension_publications/e2980/E2980-2007.PDF

Niu, J.Y., Gan, Y.T., & Huang, G.B. (2004). Dynamics of root growth in spring wheat mulched with plastic film. Crop Science, 44(5), 1682–1688. http://dx.doi.org/10.2135/cropsci2004.1682

Oliveira, J.C.M., Timm, L.C., Tominaga, T.T., Cassaro, F.A.M., et al. (2001). Soil temperature in a sugar-cane crop as a function of the management system. Plant and Soil, 230(1), 61–66. http://dx.doi.org/10.1023/A:1004820119399

Ossomi, E. M., Pace, P. F., Rhykerd, R. L., & Rhykerd, C. L. (2001). Effect of mulch on weed infestation, soil temperature, nutrient concentration, and tuber yield in Ipomoea batatus (L.) Lam. In Papua New Guinea. Tropical Agriculture (Trinidad), 78(3), 144–151.

Patil, S., Kelkar-Tushar, S., & Bhalerao, S. (2013). Mulching: A Soil and water conservation practice. Research Journal of Agriculture and Forestry Sciences, 1(3), 26–29.

Qin, W., Hu, C., & Oenema, O. (2015). Soil mulching significantly enhances yields and water and nitrogen use efficiencies of maize and wheat: a meta-analysis. Scientific Reports, 5, 16210. http://dx.doi.org/10.1038/srep16210

Ramakrishna, A., Hoang, M.T., Suhas, P.W., & Tranh, D.L. (2006). Effect on mulch on soil temperature, moisture, weed infestation and yield of groundnut in North Vietnam. Field Crops Research, 95(2-3), 115-125. http://doi.org/ 10.1016/j.fcr.2005.01.030

Ramos, L., Berenstein, G., Hughes, E. A., Zalts, A., & Montserrat, J. M. (2015). Polyethylene film incorporation into the horticultural soil of small periurban production units in Argentina. Science Total Environment, 523, 74–81. http://doi.org/ 10.1016/j.scitotenv.2015.03.142

Rangarajan, A., & Ingall, B., (2001). Mulch color effects radicchio quality and yield. Horticultural Science, 36(7), 1240–1243. https://doi.org/10.21273/HORTSCI.36.7.1240

Ranjan, P., Patle, G. T., Prem, M., & Solanke, K R. (2017). Organic Mulching - A Water saving technique to increase the production of fruits and vegetables. Current Agricultural Research Journal, 5(3), 371- 380. http://dx.doi.org/10.12944/CARJ.5.3.17.

Ren, X., Chen, X., & Jia, Z. (2009). Ridge and furrow method of rainfall concentration for fertilizer use efficiency in farmland under semiarid conditions. Applied Engineering Agriculture, 25 (6), 905–9130.

Rui, L., Qinggui, L., & Lidong, P. (2020). Review of organic mulching effects on soil and water loss. Archives of Agronomy and Soil Science, 67(1), 136-151. https://doi.org/10.1080/03650340.2020.1718111.

Ruiz, J.M., Hernandez, J., Castilla, N., & Luis, R. (2002). Effect of soil temperature on K and Ca concentrations on ATPase and pyruvate kinase activity in potato roots. Horticultural Science, 37(2), 325–328. https://doi.org/10.21273/HORTSCI.37.2.325

Sardans, J., & Penuelas, J. (2004). Increasing drought decreases phosphorus availability in an evergreen Mediterranean forest. Plant and Soil, 267(1-2), 367–377. https://doi.org/10.1007/s11104-005-0172-8

Schimel, D.S. (2010). Drylands in the earth system. Science, 327, 418–419. https://doi.org/10.1126/science.1184946.

Serrano-Ruiz, H., Martín-Closas, L., & Pelacho, A. (2021). Biodegradable plastic mulches: Impact on the agricultural biotic environment. Science of The Total Environment, 750, 141228 10.1016/j.scitotenv.2020.141228.

Silva, A. C. C. D., Nascimento, J. M. S. D., Diotto, A. V., Lima, L.A., & Oliveira, M.C.D. (2019). Yield in tomato under two water depths and plastic mulching. Revista Brasileira de Ciencias Agrarias, 14 (3), 1-6. https://doi.org/10.14295/CS.v12.3779.

Singh, G., & Singh, S. K. (2019). Effect of bio-fertilizer and mulching on growth, yield and quality of cauliflower (Brassica oleracea var. botrytis L.) in Punjab. Journal of Crop and Weed, 15(1), 182-185. https://www.cabdirect.org/cabdirect/abstract/20183080306

Singh, S.K., Raturi, H.C., & Kumar, R. (2017). Effect of different mulches and biofertilizers on qualitative and quantitative attributes of tomato. Journal of Plant Development Sciences, 9(11), 999-1005. https://www.cabdirect.org/cabdirect/abstract/20183080306

Sreejata, B., Martin-Closas, L., Pelacho, A.M., & DeBruyn, J.M. (2018). Biodegradable Plastic Mulch Films: Impacts on soil microbial communities and ecosystem functions. Frontiers in Microbiology, 9, 819. https://doi.org/10.3389/fmicb.2018.00819

Sumathi, C.S. (2010). Development of sustainable crop improvement strategies through microbial bioinoculants application in turmeric (Curcuma longa L.) plantation. Unpublished Ph.D., thesis submitted to the Bharathidasan University, Trichy, India. Pp: 35

Sumathi, C.S., Mahalakshmi, P., & Rajesh, P. (2021). Impact of mycorrhizal soil fertility proteins and Arbuscular mycorrhizal application to combat drought stress in maize plants. Journal of Plant Biochemistry and Biotechnology, 30(4), 906–917. http://dx.doi.org/10.1007/s13562-021-00745-2

Suresh Kumar, J., Nedunchezhiyan, M., & Sunitha S. (2021). Weed control approaches for tropical tuber crops - A review. International Journal of Vegetable Science, 27(5), 439-455. https://doi.org/10.1080/19315260.2020.1839156

Surya, J.N., Puranik, J.B., Zadode, S.D., & Deshmukh, S.D. (2000), Effect of wheat straw incorporation on yield of green gram and wheat, soil fertility and microbiota. Journal of Maharastra Agricultural University, 25(2), 158-160.

Tarara, J.M. (2000). Microclimate modification with plastic mulch. Horticultural Science, 35(2), 222–228.

Teame, G., Tsegay, A., & Abrha, B. (2017). Effect of organic mulching on soil moisture, yield, and yield contributing components of sesame (Sesamum indicum L.). International Journal of Agronomy, 6, 1-6. http://dx.doi.org/10.1155/2017/4767509

Tiquia, S.M., Wan, J.H.C., & Tam, N.F.Y. (2002) Microbial population dynamics and enzyme activities during composting. Compost Science Utilization, 10(2), 150–161. https://doi.org/10.1080/1065657X.2002.10702075

Uhlirova, E., Simek, M., & Santruckova, H. (2005). Microbial transformation of organic matter in soils of montane grasslands under different management. Applied Soil Ecology, 28 (3), 225-235. https://doi.org/10.1016/j.apsoil.2004.08.002.

Wang Y.P., Xiao G.L., Taotao, F., Lin, W., Neil, C. T., Kadambot H.M. S., & Feng-Min, L. (2016). Multi-site assessment of the effects of plastic-film mulch on the soil organic carbon balance in semiarid areas of China. Agricultural Forest Meteorology, 228–229, 42–51. https://doi.org/10.1016/j.agrformet.2016.06.016

Wang, Y., Liu, L., Luo, Y., Awasthi, M.K., et al. (2020). Mulching practices alter the bacterial-fungal community and network in favor of soil quality in a semiarid orchard system. The Science of the Total Environment, 725, 138527. https://doi.org/10.1016/j.scitotenv.2020.138527

Wang, Z., Li, M., Flury, M., Schaeffer, S.M., Chang, Y., Tao, Z., & Wang, J. (2021). Agronomic performance of polyethylene and biodegradable plastic film mulches in a maize cropping system in a humid continental climate. The Science of the Total Environment, 786, 147460. https://doi.org/10.1016/j.scitotenv.2021.147460

Waterer, D. (2010). Evaluation of biodegradable mulches for production of warm season vegetable crops. Canadian Journal of Plant Science, 90(5), 737–743. http://dx.doi.org/10.4141/CJPS10031

World Bank. (2002). Agenda for water sector strategy for north china (Number 22040- CHA). World Bank/ Rural Development and Natural Resources Unit, Beijing, China.

Wu, C., Yajie, M., Dan, W., Yongpan, S., et al. (2022). Integrated microbiology and metabolomics analysis reveal plastic mulch film residue affects soil microorganisms and their metabolic functions.

Journal of Hazardous Materials, 423, Part B, 127258, https://doi.org/10.1016/j.jhazmat.2021.127258

Xu, D., Ling, J., Qiao, F., Fang, Q., et al. (2022). Organic mulch can suppress litchi downy blight through modification of soil microbial community structure and functional potentials. BMC Microbiology, 22, 155. https://doi.org/10.1186/s12866-022-02492-3

Yaghi, T., Arslan, A., & Naoum, F. (2013). Cucumber (Cucumis sativus, L.) water use efficiency (WUE) under plastic mulch and drip irrigation. Agricultural Water Management, 128, 149-157. http://dx.doi.org/10.1016/j.agwat.2013.06.002

Yaşar, S., & Șahin, H. (2021). The effects of mulching with organic materials on the soil nutrient and carbon transport by runoff under simulated rainfall conditions. Journal of African Earth Sciences, 176, 104152. https://doi.org/10.1016/j.jafrearsci.2021.104152

Yin, H., Xiao, J., Li, Y., Chen, Z., Cheng, X., Zhao, C., & Liu, Q. (2013). Warming effects on root morphological and physiological traits: the potential consequences on soil C dynamics as altered root exudation. Agricultural Forests Meteorology, 180, 287–296. https://doi.org/10.1016/j.agrformet.2013.06.016

Yin, W., Chai, Q., Guo, Y., Fan, H., et al. (2021). No tillage with plastic re-mulching maintains high maize productivity via regulating hydrothermal effects in an arid region. Frontiers in plant science, 12, 649684. http://dx.doi.org/10.3389/fpls.2021.649684

Yu, Y.Y., Turner, N., Gong, Y., Li, F.M., Fang, C., Ge, Li, J., & Ye, J. (2018). Benefits and limitations to straw- and plastic-film mulch on maize yield and water use efficiency: A meta-analysis across hydrothermal gradients. European Journal of Agronomy, 99, 138- http://dx.doi.org/10.1016/j.eja.2018.07.005

Yuan, Y., Zu, M., Zuo, J., Jiajia, Z., Runze, L., & Jun, T. (2022). What will polyethylene film mulching bring to the root-associated microbial community of Paeonia ostii? Applied Microbiology Biotechnology, 106, 4737–4748. https://doi.org/10.1007/s00253-022-11986-z

Zhang, J., Sun, J., Duan, A., Wang, J., Shen, X., & Liu, X. (2007). Effects of different planting patterns on water use and yield performance of winter wheat in the Huang-Huai-Hai plain of China. Agricultural Water Management, 92 (1), 41–47. https://doi.org/10.1016/j.agwat.2007.04.007

Zhang, P., Wei, T., Cai, T., Ali, S., Han, Q., Ren, X., & Jia, Z. (2017). Plastic-film mulching for enhanced water-use efficiency and economic returns from maize fields in semiarid China. Frontiers in Plant Science, 8, 512. https://doi.org/10.3389/fpls.2017.00512

Zhang, S., Wang, Y., Sun, L., Qiu, C., et al. (2020). Organic mulching positively regulates the soil microbial communities and ecosystem functions in tea plantation. BMC Microbiology, 20, 103. https://doi.org/10.1186/s12866-020-01794-8

Zhu, L., Liu, J., Luo, S., Bu, L., Chen, X., & Li, S. (2015). Soil mulching can mitigate soil water deficiency impacts on rainfed maize production in semiarid environments. Journal of Integrative Agriculture, 14 (1), 58–66. https://doi.org/10.1016/S2095-3119(14)60845-5