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Enhancing crop yield and conserving soil moisture through mulching practices in dryland agriculture

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Dryland agriculture requires the efficient utilization of water resources and the implementation of water-conserving technologies. Mulching is a water conservation practice used in arid land areas to preserve soil moisture, control temperature, and minimize soil evaporation rates. Organic mulching minimizes soil deterioration, enhances organic matter, and boosts the soil's ability to retain water. Mulching can help keep moisture in the root zone, allowing plants to receive water for extended periods. Mulching with composted yard waste led to higher soil nutrient levels, including phosphorus (P), potassium (K), calcium (Ca), and organic matter when compared to uncovered soil. Under plastic mulch, soluble nutrients such as nitrate (NO_3^-), ammonium (NH_4^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and fulvic acid are released as organic matter decomposes, enhancing the soil's nutrient availability. Mulching has several advantages for dryland agriculture, such as reducing soil water loss, soil erosion, weed growth, water droplet kinetic energy, and competition for nutrients and water with nearby fields. This review article aimed to demonstrate the effectiveness of ground mulching in water conservation. This is particularly important in arid regions where agricultural sustainability is at risk due to drought, heat stress, and the inefficient use of limited water resources during the cropping season. Ground mulching is essential for minimizing surface evaporation and hence decreasing water loss. This review research thoroughly examines the advantages of organic and synthetic mulches in crop production, as well as their use in the preservation of soil and water resources.

KEYWORDS

soil-water conservation, organic matter, mulch, soil moisture, dry land

1 Introduction

Feeding the future population cannot be addressed solely by enhancing water productivity within current land usage, as there is a severe limitation of agricultural land (Ranjan et al., 2017). Rainfed agriculture, such as non-irrigated crops constitutes 60–70% of the world's agricultural production and occupies 80% of cropland (Li et al., 2018). Moreover, as water scarcity continues to rise, rainfed farming becomes increasingly vital in ensuring global food supply (Li et al., 2017). The scarcity of water caused by rising temperatures and unpredictable rainfall patterns is responsible for the limited crop yields in arid and semi-arid regions (Qin et al., 2015; Li et al., 2017). Hence, it is crucial to manage the water usage on farmland to preserve water resources in agricultural areas. Dryland farming prioritizes rainfed agriculture and requires the efficient utilization of water resources and the implementation of water conserving technologies (Qin et al., 2013). Consequently, in semi-arid and arid regions, globally, prudent and effective water consumption has been practiced successfully over an extended period.

Kader et al. (2017) revealed that mulching is done by covering the soil surface around plants with organic or synthetic material to increase plant development and improve agricultural output. In dryland agriculture, the focus is on rainfed production, which demands the deployment of water-conserving technology to optimize the effective use of available water. Qin et al. (2013) and Yu et al. (2018) indicated that mulching boosts crop growth and production and improves water efficiency.

Furthermore, mulches can be classified as either inorganic, composed mostly of plastic-based components, or organic biodegradable materials (Kader et al., 2017). According to Adhikari et al. (2016) both categories have grown in popularity in recent years. Another research by Adeboye et al. (2017) reported in different areas, crop production and soil hydrothermal conditions were found to be impacted by the addition of different biodegradable and inorganic mulches following rainfall. It is crucial for dry land farmers to comprehend how much mulching boot crop yields while preserving soil moisture. Mulching in dryland agriculture gives advantages such as moisture retention, temperature regulation, weed suppression, soil health advancement, and erosion control, boosting water resource efficiency and crop yields (Kishore et al., 2022). Mulch works as a protective layer, decreasing nutrient leaching and runoff produced by heavy rainfall or irrigation. It slows down water flow, conserving nutrients in the root zone, and making them more available to plants (Qiu et al., 2020). Mulch also offers a home for beneficial soil microorganisms, which play a critical role in nutrient cycling and plant uptake (De Biman et al., 2021).

Mulch is a helpful technique for minimizing soil erosion by covering the soil surface, absorbing rainwater, and slowing flow velocity. This is particularly effective in sloping landscapes or places with vulnerable soil conditions (Fernández, 2023). Mulch also preserves topsoil, guaranteeing its preservation and availability for plant absorption. It also offers a good habitat for beneficial organisms like earthworms, insects, and bacteria, which play a critical role in soil health and nitrogen cycling, hence boosting nutrient availability and ecosystem health (Barajas-Guzmán et al., 2006).

Mulch, especially organic mulch derived from plant residues, contributes to carbon sequestration in soil by supplying organic matter and boosting soil organic carbon concentration (Chen et al., 2018). This not only enhances soil fertility and structure but also helps avoid climate change by absorbing carbon dioxide (Chen et al., 2018). Organic mulches may impact soil pH, with strong acid components like pine needles lowering it over time, while high alkalinity components like wood ash increase it (Larkin, 2020). Understanding these pH-modifying capacities may assist manage soil pH levels and generate optimum growing conditions for diverse crops (Larkin, 2020). Different mulches also alter nutrient availability and absorption for certain crops, boosting nutrient management approaches and overall use efficiency (Jain et al., 2017).

Therefore, the overall objective of this review paper was to assess the effects of mulch on crop yield and soil moisture conservation in arid areas.

2 The potential of mulching for sustainable soil and water conservation in agricultural practices

Spreading different materials over a field before or after planting is a common agricultural practice known as mulching, which helps to increase crop yields and soil quality. As mulching materials, you can use plastic, agricultural waste, animal dung, sand, and pebble (Gan et al., 2013). Mulching's main objectives are to limit weed growth, improve moisture retention, increase soil warming, and decrease water evaporation (Gan et al., 2013). According to studies, mulching can boost crop growth, yields, and water use (Chaudhary et al., 2003; Abdrabbo et al., 2017; Yu et al., 2018; Ali Mozaffari, 2022).

2.1 Types of mulching materials

The three categories of mulching materials are defined as organic, inorganic, and special by Kader et al. (2017). Animal manure, wood debris, leftover processed foods, and agricultural waste may all be utilized to generate organic mulching materials. Inorganic mulching materials include synthetic plastics and plastics made from polyethylene sheets, according to Kader et al. (2017). Similarly, Adhikari et al. (2016) have also created environmentally friendly products that are adaptable and simple to use, such as surface coatings, biodegradable polymer films, and compostable and photodegradable plastic films that are essential for use in agriculture.

2.1.1 Organic mulches

The best time to apply organic mulch, which is made from plant or animal matter, is right after crop germination. According to Goodman (2020), organic mulches have numerous benefits, including reducing nitrate leaching, improving soil physical properties, promoting microbial activity, balancing the nutrient cycle, enriching the soil with nutrients, regulating temperature, improving water absorption by the soil, and preventing erosion. Organic materials, on the other hand, are difficult to employ for crop production and need a substantial amount of effort. As a result, due to economic and logistical restrictions, the use of organic mulch in horticulture production has been limited (Zhao et al., 2014).

2.1.1.1 Wood chips

For gardening, landscaping, and horticulture, wood chips composed of shredded or chipped wood are used. We won't have to weed by hand or apply herbicides as often since they block the sun and stop weed seeds from growing (Bantle et al., 2014). In addition to providing insulation, its barrier effect decreases soil moisture retention and evaporation. improved soil structure, increased microbial activity, and reduced soil erosion are all long-term benefits of using wood chips (Zheng et al., 2022).

2.1.1.2 Straw mulch

For protection in the garden and on the farm consideration of straw mulch made from the stalks of cereal crops is important. It protects soil from excessive temperature changes, prevents weeds from growing, and retains soil moisture. Because it preserves soil particles and lessens the effect of rain and wind, it stops soil erosion (Ma et al., 2024). Straw mulch, when let to decompose, adds organic matter to the soil, which in turn improves soil structure, nutrient availability, and the populations of beneficial soil organisms (Goodman, 2020).

2.1.1.3 Sawdust mulch

In landscaping and gardening, sawdust mulch made from finely ground or chipped wood waste is used to inhibit weed growth by obstructing sunlight. However, it may still enable weeds to sprout if sprayed lightly (Davis and Strik, 2022). Sawdust absorbs moisture and holds moisture, but its high carbon content may contribute to nitrogen depletion in the soil. Some woods, like pine or cedar, may make sawdust acidic, influencing soil pH. In addition to potentially stunting plant development, sawdust takes longer to decompose than other organic mulch materials (Tan et al., 2016).

2.1.1.4 Bark mulch

Bark mulches are organic mulches created from tree bark, and used in landscaping and gardening for their aesthetic appeal and practical advantages (Łukasiewicz, 2013). They generate a thick covering that discourages weed growth, lowers evaporation, and helps keep moisture in the soil. They also operate as a barrier, providing insulation, and reducing soil erosion. Bark mulches break down slowly and may endure for many years, making them a durable alternative for mulching. Different varieties of bark have unique features (Kosterna, 2014).

2.1.1.5 Newspaper mulch

Newspaper mulch is an eco-friendly, affordable, and ecologically acceptable solution for weed control and soil moisture retention in gardens and landscapes (Puka-Beals and Gramig, 2021). It inhibits sunlight, stops weed seeds from developing, and serves as a physical barrier to suffocate existing weeds. Newspaper mulch conserves soil moisture by minimizing evaporation, making it advantageous in dry climates. The degraded wood pulp of newspaper supplies organic matter to the soil, enhancing soil structure and fertility (Puka-Beals and Gramig, 2021). It offers insulation, moderating soil temperature, and offering protection during cold times. Newspaper is widely accessible and commonly thrown as garbage, making it a sustainable alternative to other mulch materials (Haapala et al., 2014).

2.1.1.6 Compost mulch

Compost mulch is a nutrient-rich mulch formed from decomposed organic debris, which increases soil health and plant development (Mallory and Smagula, 2014). It distributes vital nutrients like nitrogen, phosphate, and potassium into the soil, increasing soil structure and boosting microbial activity. Compost mulch also increases soil moisture-holding capacity, aeration, and drainage, and helps reduce weed development by burying weeds and preventing seed germination (Paradelo et al., 2012). It also offers insulation, controlling soil temperature, and guarding against frost during colder months. Overall, compost mulch is a good and nutrient-rich solution for plant health (Mallory and Smagula, 2014).

2.1.2 Inorganic mulches

Plastic mulch is widely utilized in industrial crop cultivation, the most popular forms being polyvinyl chloride and polyethylene films. Because these plastic coatings are more permeable to long-wave radiation, they can raise the temperature around the crop during winter nights. As a result, Gosar and Baričevič (2011) propose that polyethylene mulch is the best material for horticultural crop development. In another study by Gao et al. (2019), many plastic films produced from various polymers, including polyvinyl chloride (PVC), high-density polyester (HDPE), and low-density polyethylene (LDPE), were studied for mulching applications in the 1960s. Because of its convenience, LLDPE is the most often used plastic mulching material. Because of their great results, black plastic mulch films have become increasingly popular, particularly in dry and semi-arid locations. According to Qin et al. (2014), using black polyethylene mulch boosted crop output and quality, increased soil water content, and transformed the soil microbial community, resulting in greater financial returns for farmers. According to Serrano-Ruiz et al. (2021), the "plastic culture" farming approach, which involves utilizing plastic as mulch, is increasingly being used to produce fresh vegetables. In addition, Yu et al. (2018) indicated that around one million tons of synthetic mulch material are consumed worldwide every year.

In Spain, for example, the utilization of plastic film as mulch in greenhouses grew by 5.7% in 2012, reaching 60,000 hectares (Market, 2016). According to Daryanto et al. (2017), China uses forty percent of the globe's mulch made from plastic each year, or

0.7 million tons, and presently utilizes eighty percent of the world's film made from plastic mulch, coupled with Japan and South Korea (Zhao et al., 2022). Plastic mulching enhanced wheat and maize yield in China by roughly 33.2% and 33.7%, respectively (Li et al., 2016).

2.2 Benefits of mulching

Mulching gradually improves air circulation around plants, soil particle aggregation, soil fertility, and permeability (Kader et al., 2017). Mulch functions as an insulator, shielding the soil from hot and cold temperatures. Mulch treatments help agricultural fields in different ways, including decreased soil water loss, soil erosion, raindrop influence on the surface of soil, weed growth, and competition for nutrients and moisture from nearby fields (Yang et al., 2015; Kader et al., 2017). As observed by Qin et al. (2015) mulches are especially useful in the summer because they prevent soil moisture loss owing to evaporation. Mulch may also increase the structure of the soil and nutrient circulation by boosting earthworm mobility in soil pores (Qin et al., 2015). Moreover, mulching also decreases soil pH, which improves nutrient accessibility (Larentzaki et al., 2008). According to Larentzaki et al. (2008), who noted that organic mulch decomposes over time, replenishing the soil with nutrients and improving the soil's capacity to maintain long-term access to nutrients.

Because of its impermeability to gas movement, plastic mulch acts as a dependable barrier for fumigants and protects against sun exposure. However, it can have surprising implications on soil health and pest control (Chalker-Scott, 2007). Mulch increases efficient fertilizer usage and lowers nutrient leaching by retaining nutrients in the crop's roots area, resulting in better soil health. Mulch also increases the attractiveness of the surroundings by providing a consistent appearance. Soil is a complex ecosystem in which crop type, water retention, topsoil and crop water loss, and rainfall penetration all affect the amount of water present (Li et al., 2013; Ma et al., 2018). Plants need a range of temperatures and moisture from the soil at various stages of growth. According to Kader et al. (2017), organic mulching lowers soil degradation, promotes organic matter, and raises the soil's capacity to retain water. Figure 1 demonstrates the advantages of mulched and un-mulched soil interactions with plants and environmental systems.

2.3 Potential agricultural and environmental benefits of mulches

Research has shown that the use of mulching may effectively mitigate soil water loss in arid regions by decreasing evaporation (Yang et al., 2015; Kader et al., 2017). Plastic mulch that blocks moisture seeps into the soil by re-forming evaporated water and allowing it to return as droplets. This increases the length of time that moisture can be stored, allowing for longer intervals between irrigations and a reduction in the water required to produce crops (Kader et al., 2017). Plastic mulching works better than straw mulching in terms of preserving soil water (Li et al., 2017). Two further significant benefits of mulching are that it lessens soil erosion and surface evaporation (Qin et al., 2016). It also helps to keep moisture around plants root zone, making water available to them for longer periods of time (Tuure et al., 2021).

According to Qin et al. (2016), the primary advantage of mulching is its ability to maintain soil moisture by minimizing soil loss and lowering surface water loss. As Figure 2 demonstrates, in agricultural operations, mulching helps to conserve soil water by decreasing evaporation and managing the soil's temperature (Kader et al., 2017). Understanding the soil temperature and water transport mechanisms under the mulch layer is crucial for enhancing system accessibility for efficient mulching (Kader et al., 2017; Li et al., 2018). Figure 3 depicts a Schematic illustration of how sustainable agriculture interferes with changing temperatures and crops.

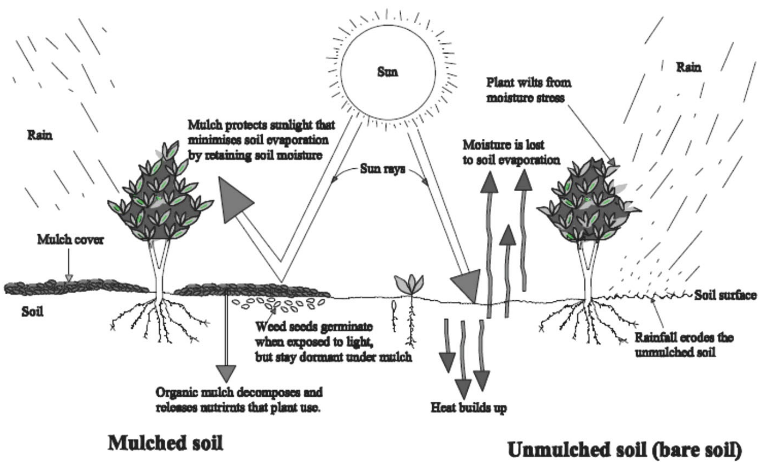

FIGURE 1
Advantages of mulched and unmulched soil interactions with plants and environments. Reproduced from Kader et al. (2017). Used with permission of Elsevier Science & Technology Journals, from "Recent advances in mulching materials and methods for modifying soil environment", M. A. Kader, M. Senge, M. A. Mojid, and K. Ito, *Soil and Tillage Research* vol. 168, May 2017; permission conveyed through Copyright Clearance Center, Inc.

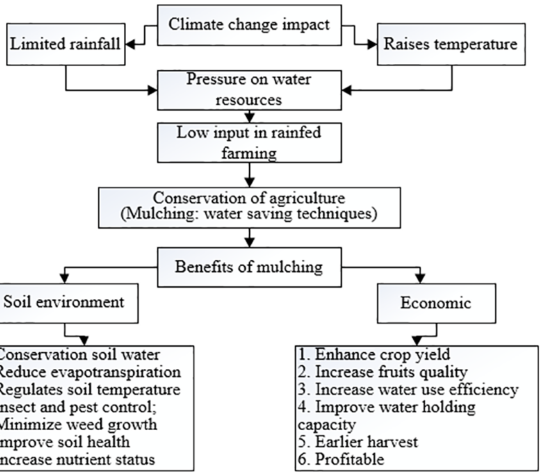

FIGURE 2
The diagram demonstrates sustainable agriculture that interacts with the climate and crops. (Adapted from Figure 1 of Kader et al., 2019 under CC-BY 4.0 license.)

2.3.1 Effects of mulch on soil and water conservation

Mulching it is extremely effective for maintaining moisture availability in arid regions by slowing the rate of evaporated water (Yang et al., 2015; Zribi et al., 2015; Kader et al., 2017). Mulching with moisture barrier plastic film is particularly effective because it keeps soil moisture from evaporating under the covering of mulch films and then condenses to return to the soil as minute droplets of water (Kader et al., 2017). This helps to keep soil moisture in place for many days, extending the time between irrigation and minimizing the demand for irrigation throughout the growth season. According to Li et al. (2013), plastic mulching is far more successful than straw mulching at conserving soil water. The fundamental benefit of mulching is its capacity to prevent surface evaporation, retaining soil moisture while simultaneously minimizing soil erosion (Dass et al., 2013; Qin et al., 2016).

According to Li et al. (2018) and Kader et al. (2019), both water and heat transfer pathways are critical for the optimal utilization of mulching materials. El-Beltagi et al. (2022) emphasize the need of selecting proper mulching materials in order to reduce the frequency of watering required during crop production. Mulching can help keep moisture in the root zone, allowing plants to receive water for extended periods of time (Kazemi and Safari, 2018). According to Safari et al. (2021), mulched soil evaporates at a slower pace than bare soil. Figure 4 demonstrates a comparison technique for covered and uncovered soil/crops.

2.3.2 Soil temperature

According to Steinmetz et al. (2016), plastic mulch can transmit a significant percentage of the heat it absorbs to the soil. The temperature of the soil changes throughout the year, particularly during extreme heat and cold periods and from day to night. Mulches operate as an insulator, keeping the soil temperature stable. Mulch with a higher water content reduces evaporation, which helps to regulate soil temperature. However, various variables impact soil temperature. White mulches chill the soil, whereas clear

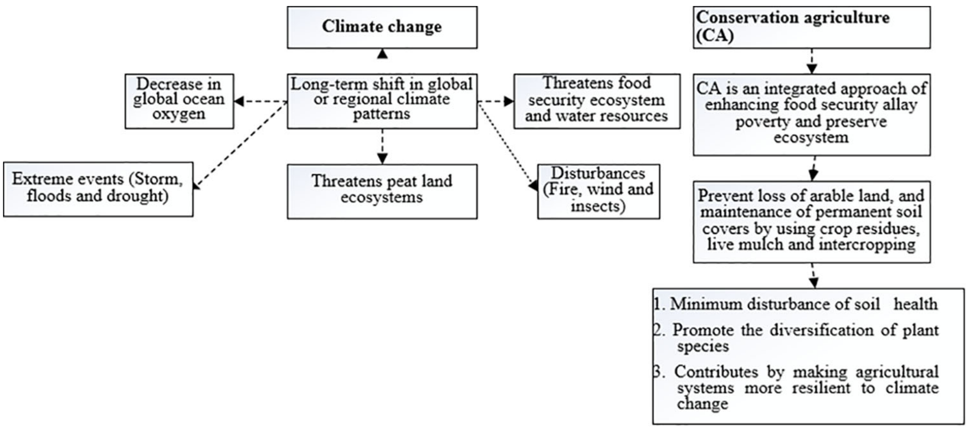

FIGURE 3
A schematic diagram of how conservation agriculture interacts with climate change and crops. (Adapted from Figure 1 of El-Beltagi et al., 2022 under CC-BY 4.0 license.)

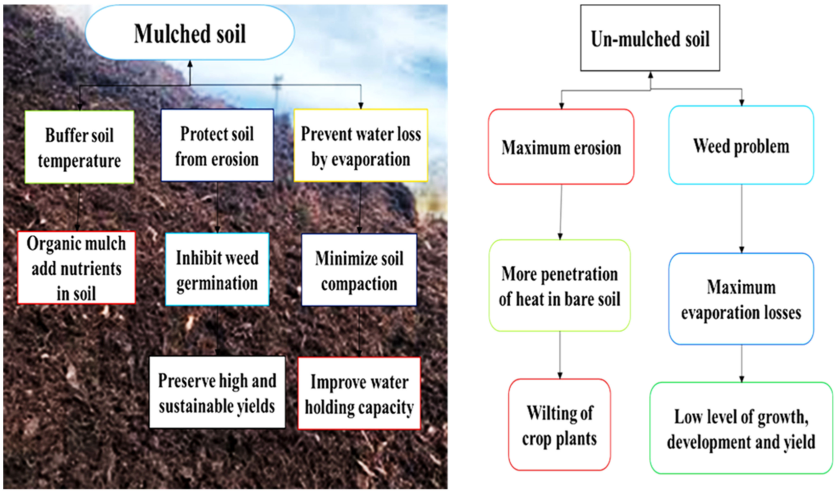

FIGURE 4
Comparison technique for covered and uncovered soil/crops. (Reproduced from Figure 3 of El-Beltagi et al., 2022 under CC-BY 4.0 license.)

plastic mulches heat it up. Black plastic mulch is more efficient than bare soil in boosting soil temperatures due to increased radiation absorption (Rajablariani et al., 2012). According to Tan et al. (2017), compost mulch may manage soil temperature by minimizing the daily variance and providing a more stable environment ideal for root activity.

Mulching layers control temperature by sheltering the soil against direct sunshine and minimizing soil water evaporation (Bakshi et al., 2015). Mulching with organic matter may lower soil temperatures by more than 10°C compared to bare soil, as observed in research done in hotter areas or throughout the summer, according to (Chalker-Scott, 2007). Particularly, soil temperature increased by 0.9 to 4.3°C during the seedling stage, 1.6 to 2.3°C during the bud initiation stage, and 0.8 to 1.9°C during the flowering stage (Xie et al., 2005). Another study by Subrahmaniyan and Zhou (2008) found that a transparent, photodegradable polythene films raised the soil temperature by 2.9 to 3.30°C. In early May, the temperature difference between mulched and bare soil for transparent film and black film reached 7°C and 5°C, respectively. Rajablariani et al. (2012) observed that in comparison to bare soil, the average temperature of soil rose by 3 to 6°C below different colored plastic mulches. Table 1 outlines the influence of different types of mulch on the soil's temperatures in various crops and Table 2 outlines the impact of mulching on soil moisture and temperature when compared with no mulch.

2.3.3 Soil compaction

Mulching preserves the soil's structure against compaction induced by excessive rainfall or foot activity by serving as a shield (Bashir et al., 2017). Simple mulches like straw have been demonstrated to promote soil stability in aggregates, enhancing the soil's capacity for water infiltration and deeper layer aeration. Bark mulch, for example, can distribute the direct contact of water droplets, feet, and tires, recovering soil aggregation and porosity. Iqbal et al. (2020) suggested that mulch should be applied before compaction occurs rather than after. Mulching has been shown to alter the relationships between soil management elements, such as organic material content, the activity of microbes, availability of nutrients, decrease of soil eroding and compacting, and temperature control (Tellen and Yerima, 2018).

2.3.4 Soil nutrient

Mulching helps keep nutrients near the plant roots, ensuring their efficient utilization and reducing fertilizer leaching. For a more visually appealing landscape, uniform mulching is preferred (Li et al., 2013; Ma et al., 2018). After organic mulch decomposes, the soil's organic content increases rapidly, enhancing its water storage capacity (Kader et al., 2017).

Mulch acts as a barrier between the soil and external factors, preserving soil nutrients and promoting a healthy soil composition. In a similar study, Kasirajan and Ngouajio (2012) discovered that the use of black polythene mulch reduced nitrogen transport and leaching while enhancing bean crop utilization. Fang et al. (2011) observed that mulching with composted yard waste led to higher soil nutrient levels, including phosphorus (P), potassium (K), calcium (Ca), and organic matter when compared to uncovered soil. Additionally, mulching increased soil cation exchange capacity (CEC), total microbial biomass, and organic matter, while also enhancing water availability and soil porosity, resulting in better mineral absorption. Based on the research by Marwein (2016), the use of mulch increased the total phosphorus concentration in the soil, with levels rising from 601–658 mg kg^{-1} after four years and 491–694 mg kg^{-1} after eleven years.

The introduction of organic acids into the soil through the decomposition of organic matter beneath plastic mulch can lower soil pH and increase the bioavailability of micronutrients such as manganese (Mn), zinc (Zn), copper (Cu), and iron (Fe). Grewal (2020) found that Fe and Zn levels were elevated in the soil beneath plastic mulch, supporting this claim. Over time, the mineralization of organic nitrogen also increases the availability of nitrogen in the soil. Under plastic mulch, soluble nutrients such as nitrate (NO_3^-),

TABLE 1 Impact of various mulch types on the soil temperature in different crops.

Type of mulch	Impact on soil temperature	Crop	References
polyethylene or straw mulch	Decrease soil temperature	Maize and wheat	(Yin et al., 2016)
Straw mulch	Minimize soil temperature fluctuations	Alfalfa	(Jun et al., 2014)
	Reduce temperature of soil	Maize	(Li et al., 2012)
	Reduce the temperature in the soil	Wheat–maize	(Li et al., 2022)
Black mulch made of plastic.	Increase soil temperature	Cucumber	(Torres-Olivar et al., 2018)
	Increase soil temperature	Maize	(Xiukang et al., 2015)
	Boost soil temperature	Maize	(Li et al., 2012)
	polyethylene mulched plots than white-on-black	Lettuce	(Gheshm and Brown, 2020)
	polyethylene or bare surface plots		
Transparent mulch made of plastic	The soil temperatures rose with the application of plastic mulching	Maize	(Li et al., 2022)
	Reduce soil temperature	Maize	(Li et al., 2022)
	Increase soil temperature	Potato	(Zhao et al., 2012)
	Increase soil temperature	Maize	(Li et al., 2022)
Compostable film as mulch	Maximize soil temperature	Maize	(Li et al., 2012)
	Reduce soil temperature	Tomatoes	(Jia et al., 2020)
	Boost soil temperature	Different crops	(Chen N. et al., 2021)
Compost mulch	Maximize soil temperature	–	(Guo et al., 2020)
Silver/black plastic mulch	Increase soil temperature	Cucumber	(Torres-Olivar et al., 2018)

ammonium (NH_4^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and fulvic acid are released as organic matter decomposes, enhancing the soil's nutrient availability (Thapa et al., 2022). Table 3 outlines the impact of mulching on soil fertility.

2.3.5 Moisture retaliation in the root zone

The application of mulch may prevent evaporation from the soil, which helps to maintain moisture levels around plant roots and increases the time available for plants to utilize water. As a consequence, the use of mulch may minimize the demand for irrigation in covered regions (Ranjan et al., 2017). For plants to retain moisture in their roots, mulch is an essential component. Plants can retain more water for longer because this protective layer decreases evaporation by shielding them from wind and sunshine (Tang et al., 2022). As an insulating layer, it controls soil temperature, reduces heat stress, and maintains consistent soil moisture levels. By reducing the rate at which water moves over the soil's surface, mulch also reduces runoff, which means that more water makes it to the root zone (Suburika et al., 2018). It prevents weeds from growing, which means less water is available for the roots and less watering is required. Mulches made of organic materials enhance soil structure as they decompose; this, in turn, increases the soil's ability to hold water and provides more moisture for plant roots (Fonteyne et al., 2020).

2.3.6 Increase the infiltration rate

Mulching can decrease surface runoff and improve the retention of rainwater on the soil surface, allowing water to penetrate the soil for a longer duration (Eid and Negm, 2019). Conservation agriculture resulted in a reduction of irrigation water required by increasing the infiltration rate for crop production (Belay et al., 2019). In high-potential areas of Zimbabwe, mulching was found to significantly decrease surface runoff and increase infiltration, based on experiments conducted (Erenstein, 2002). Mulch, especially compost or wood chips, may improve soil structure by increasing organic matter, which in turn increases water retention and decreases runoff (Rasyid et al., 2018). It prevents soil crusting and rainwater runoff by acting as a protective layer. Mulch promotes soil porosity by producing air pockets, enabling water to travel easily through the soil profile (Čižková et al., 2021). The total penetration rate is increased when water penetrates the soil via the mulch layer. Furthermore, mulch lessens surface compaction, which in turn limits the circulation of water. By providing a cushioning effect, mulch lowers foot traffic and prevents heavy equipment from compacting the soil surface, enabling water to infiltrate the soil more quickly, thereby boosting the infiltration rate (Baker et al., 2021).

2.3.7 Effect of mulching in weed management

Mulch may cover the soil surface or operate as a material barrier and limit weed growth or physically regulate seedling emergence (Khan et al., 2022; Kaur et al., 2024). The lowest weed intensity was found in plots with polyethylene and straw mulch in comparison with plots with chemical mulch and without mulch. Weed management with and without mulch has documented considerable disparities between plots of various crops (Yadav et al., 2018). Mulch is a simple technique for managing weed populations in nurseries as well as in the field. However, to date, the weed reduction phenomena have not been thoroughly understood (Iqbal et al., 2020). When mulch is applied on the soil surface, it functions as a barrier to light transmission, decreasing the germination of small-seeded weeds. Different kinds of coatings (15 different types of coatings) were utilized compared to no coating, and the research findings revealed that there was little variation among all types of coatings, however, there were substantial changes in weed reduction when treating bare soil (Kader et al., 2019).

Mulch serves as a barrier to weed development (Ahmad et al., 2015, 2020); nevertheless, when organic mulches break down, they rapidly rise to the land's surfaces. Some natural mulches also have an allergenic impact and produce toxic compounds that are good for weed control. Additionally, the habitat generated by mulch is excellent for beneficial bacteria that feed on weed species or seeds from weeds (Chalker-Scott, 2007). Likewise, living mulch is effective in suppressing weeds by competing for fundamental resources like light, moisture, nutrients, and oxygen. They also have therapeutic benefits on weeds. Various crops for cover and mulches also assist in minimizing weed seed germination and establishment (Iqbal et al., 2020).

2.3.8 Water saved by mulching

The application of mulch is an effective water conservation method done in arid locations to maintain soil moisture, moderate temperature, and limit soil evaporation (Yang et al., 2015; Kader et al., 2017). The findings of Zribi et al. (2015) show that surface mulching is a popular strategy of water conservation in agricultural systems that rely on rainfall. Li et al. (2013) discovered that wheat straw mulch is less successful in keeping soil moisture in check than plastic sheet mulch. Qin et al. (2015) noted that mulching's primary advantage is its ability to preserve soil moisture by minimizing water loss from the soil surface and erosion of soil. Kader et al. (2017) stated that mulching manages soil temperature and reduces soil evaporation to conserve soil water, lowering the need for irrigation during crop cultivation seasons. According to Li et al. (2019), in order to increase system availability, mulching is essential for efficient heat and water transfer mechanisms. It is challenging to estimate how much water is conserved by mulching because of the interplay between the environment of the soil, plant development, and microclimate (Steinmetz et al., 2016). The impact of different mulches on soil water content is presented in Table 4.

2.4 Benefits of mulching in dryland agriculture

The kind of material, ecological location, color, thickness, perforation, and availability of resources, as well as the practicality of growing crops, all influence the choice of an acceptable mulching material (Li et al., 2017). When choosing a mulch, it's crucial to take certain traits into account. Avoid using agricultural debris as mulch since it raises the possibility of spreading pests or viruses to farmed crops. Additionally, avoid using mulch that has weed seeds in it.

By slowing the rate of evaporation, mulching is a useful method for preserving soil moisture, especially in dryland environments (Zribi et al., 2015; Kader et al., 2017). By enabling soil moisture to evaporate under the mulch layer and then condense again in the soil as droplets of water, plastic mulch with moisture-blocking qualities keeps soil moisture from leaving and may even improve soil moisture availability. Since the soil moisture is kept for many days, this helps to lengthen the application interval and decrease the need for irrigation throughout the crop growth season (Yang et al., 2015; Kader et al., 2017). Li et al. (2013) found that mulching with plastic is far more successful in retaining soil water than mulching with straw. By encouraging soil aeration around the plant, aggregating soil particles, and enhancing water drainage, mulching may increase soil productivity (Kader et al., 2017). Mulching provides several benefits for dryland agriculture, including the mitigation of soil erosion, water droplet kinetic energy, weed development, soil water loss, and competition for nutrients and water with neighboring fields (Yang et al., 2015; Kader et al., 2017). According to Qin et al. (2015), mulch may also help improve soil structure and guide nutrient flow as a result of earthworm migration into the soil. It may also decrease the pH of the soil, which increases the availability of nutrients. Plastic mulch is marketed as a stronger process wall and as being impervious to gas migration.

2.5 Role of mulching on crop production

The majority of research on mulching has been on how it affects agricultural productivity or output. López-Tolentino et al. (2016) in cucumber and Wang et al. (2021) in maize have shown that black plastic mulch may boost crop yields in the

TABLE 2 Impact of mulching on soil moisture and temperature when compared with no mulch.

Mulch type	Findings	References
PE mulch	Reduces soil temperature by 10°C	(Kuniga et al., 2018
Black plastic mulch	5°F higher bare soil at a 2-inch depth	Kumari et al., 2016
	28.4% higher moisture content than bare soil	Ashrafuzzaman et al., 2011
Wheat straw	Enhanced soil moisture by 10% over bare soil	McMillen, 2013
	Temperature increases of 2–30°C	(Bhardwaj, 2013)
Transparent film	Soil temperature increases by 7.9–10.2%	(Yang J. et al., 2022)
Black film	Soil temperature increases by 4.1–4.7%	(Qin et al., 2022)
Plastic film mulching	Soil temperature increased by 4.4°C compared with no mulching	(Duan et al., 2021)
Transparent film	Increased soil temperature by 3.8°C	(Li et al., 2021)
Black polyethylene film	Increased water use efficiency by 23.1%	(Lu et al., 2020)
Paddy straw	Increased moisture by 21.49% when compared with no mulch	(Danish et al., 2020)
Black plastic mulch	35.1%	(Malik et al., 2018)
Transparent plastic mulch	32.7%	
Plastic film mulched ridge and straw-mulched furrow	Increase soil moisture by 25.0%	(Chen Q. et al., 2021)

early stages of growth. Strawberry establishment may be accelerated and increase in yield by using biodegradable plastic mulches (Berglund et al., 2006). More study has been done on layer mulches in crops than on other kinds of mulch. Pine bark performed better than live sedum mulch in research on the impact of mulch types on vegetable output in a green roof system (Whittinghill et al., 2016).

To ensure effective growth of potato tubers, the soil temperature must be maintained between 16 and 20°C (Adamchuk et al., 2016). Dry conditions and temperatures higher than the ideal range can negatively impact tuber production, resulting in tuber malformation or chain sprouting of new, small tubers due to poor vegetative conditions. High temperatures can also lead to a reduction in the amount of storage components like starch, resulting in a change in tuber quality (Ávila-Valdés et al., 2020). Worldwide, mulch is produced from natural sources like organic matter, straws, and other agricultural waste; one easy and useful mulch source is cereal straw (Sabatino et al., 2018). Straw mulch treatment provides various advantages, including simplicity of application, lower soil temperature, less temperature changes during the day, and enhanced soil moisture. The effects of different mulches on various plants, such as tomatoes and eggplant, have been investigated (Rodan et al., 2020). According to Abdrabbo et al. (2017), the reaction of plants to plastic mulch is impacted by the kind of plant materials utilized and the surrounding environment. A study by Yin et al. (2012) found that mulching improved sweet cherry crops' water status. Additionally, mulches encourage the establishment of roots, which benefits plant expansion and growth (Kader et al., 2019). The effects of mulching on crop production are shown in Table 5.

TABLE 3 Impact of mulching on soil fertility.

Mulch type	Findings	References
Paddy straw	Increase organic carbon by 27.27%	(Shashidhar et al., 2008).
Sun hemp waste	Increase organic carbon by 32.4%	
Plastic film-mulched ridge and straw-mulched furrow	Increase soil organic carbon by 8.9%, NO_3^- by 228.7%, TN by 9.6%, AP by 21.9% and AK by 17.4%	(Chen Q. et al., 2021)
Maize residue	Straw return significantly increased soil SOC content by 9.0% and TN content by 7.1%	(Yang L. et al., 2022)
Straw mulch	Total organic carbon significantly increased by 44.46%	(Zhou et al., 2019)
Poultry manure	Increased Organic matter by 27.2% increased total nitrogen by 27.2% and increased phosphorous by 34.26% when compared to the control.	(Mehmood et al., 2014)
Weeds and dhaincha mulching	higher than the control by 5.3 g kg^{-1}	(Kalita, 2022)

TABLE 4 Impact of different mulches on the moisture content of the soil.

Mulch type	Effect on soil water	References
Plastic mulch	Increase soil water holding capacity	(Zhao et al., 2012)
	Increase soil water holding and availability	(Jabran et al., 2015)
	Maximize moisture contents and maize productivity	(Lee et al., 2019)
Degradable film mulch	Maximize soil water availability	(Li et al., 2012)
	Increase soil water content	(Li et al., 2012)
	Improve soil water holding capacity	(Song et al., 2019)
Straw mulch	Boost the availability of soil moisture	(Torres-Olivar et al., 2018)
	lower water requirements and higher water production	(Jat et al., 2015)
Sand mulch	Increase water content in the soil	(Song et al., 2019)
Compost created from municipal garbage	An 85% rise in the percolation of water	(Agassi et al., 1998)
Oats straws and olive twigs as mulch	less water lost during precipitation	(García-Orenes et al., 2009)
Transparent plastic mulch	increased humidity in the canopy air and soil water content	(Snyder et al., 2015)
Black plastic mulch	increased soil temperature, moisture content, and maize morphological requirements	(Javaid et al., 2022)
Straw strip mulching	The use of plastic film mulch and straw strip mulch increased the biomass yield (WUEb) or grain yield (WUEr)'s water usage efficiency.	(Liu et al., 2022)
Transparent film (W), black film (B), or straw mulching (S)	Mulch boosted the moisture content in the soil	(Qin et al., 2022)

2.6 Negative impact of mulching

The cost of labor, transportation, removal, and disposal of mulch can be high. The close contact of the plastic film with the soil can lead to soil fragmentation and contamination, as noted by Steinmetz et al. (2016). Grass and straw, which are commonly used types of organic mulch, contain seeds that can promote weed growth and release acid into the soil (Chalker-Scott, 2007; Patil et al., 2013). Organic mulch materials, particularly newspaper, can also be impacted by wind. Gonzalez-Dugo et al. (2014) found that the films burned and dumped on-site by farmers significantly contaminated the soil. The plastic film fragments that are discarded and buried in the arable land layer can slow crop growth.

Mulching is helpful for plants, but excessive or inappropriate application may lead to negative repercussions. Overly wet mulch

TABLE 5 Impact of mulching on crop yield.

Economic Yield in tons h^{-1}				
Crop	Unmulch	Mulch	% Increase in yield	References
Pickling cucumber	2.45	4.50	83.7	(Torres-Olivar et al., 2018)
Maize	4.18	7.18	71.77	(Xiukang et al., 2015)
Brassica napus	3.97	5.90	48.4	(Gu et al., 2017)
Sesamum indicum	0.21	0.73	16.55	(Teame et al., 2017)
Apple trees	27.9	34.7	24.4	(Liao et al., 2021)
Watermelon	22.8	48.3	111.8	(Gordon et al., 2010)
Potato	3.20	5.81	81.5	(Zhao et al., 2012)
Beetroot	2.62	6.42	145	(Yordanova and Gerasimova, 2015)
Tomato	6.02	8.27	27.20	(Moursy et al., 2015)
Chickpea	5.91	7.32	19.26	(Fetri et al., 2015)
Cotton	1.67	2.22	24.77	(Ahmad et al., 2015)
Mustard	0.41	0.61	32.78	(Saikia et al., 2014)
Rice	5.39	6.83	21.08	(Devasinghe et al., 2015)
French beans	12.73	14.10	9.71	(Kamal et al., 2012)
Lentil	0.80	0.89	10.11	(Alami-Milani et al., 2013)
Wheat	5.261	5.863	89.7	(Luo et al., 2022)
Maize	2.49	4.76	47.68	(Hashim et al., 2013)
Mung beans	1.02	1.36	25.00	(Jiang et al., 2012)
Soybean	1.32	1.57	15.92	(Arora et al., 2011)

may provide a permissive environment for root rot and fungal infections, thus it's vital to monitor soil moisture levels and regulate the mulch thickness (Souza et al., 2022). Mulch may also attract pests, such as termites, and can temporarily tie up nitrogen in the soil, producing stunted growth or fading leaves (Caboň et al., 2021). To offset this, incorporating aged or decomposed mulch or supplement nitrogen fertilizer is necessary. Certain mulches, such as pine needles or oak leaves, might gently acidify the soil, helping acid-loving plants but adversely hurting neutral or alkaline plants. It's crucial to examine the pH needs of plants and pick mulch appropriately. Thick amounts of organic mulch may block gas exchange, reducing oxygen supply to roots and fostering anaerobic conditions (Juhos et al., 2023).

2.7 The economic advantage of mulching crop

mulching offers several economic advantages by improving water efficiency, reducing weed competition, enhancing soil fertility, controlling erosion, minimizing pest and disease issues, and decreasing labor and maintenance requirements (Dong et al., 2018). By implementing mulching practices, individuals and businesses can realize cost savings, higher yields, and improved overall productivity (Kader et al., 2019). While not directly economic, mulching can have positive environmental implications that can indirectly impact the economy. For example, mulching helps conserve water resources, reduce soil erosion, and minimize nutrient runoff, which can improve water quality. These environmental benefits can have long-term economic gains by reducing costs associated with water treatment or soil remediation (Blaise et al., 2021).

It is important to note that the economic implications of mulching can vary depending on factors such as the specific crop or plant, regional conditions, scale of operations, and the overall management practices employed (Dabi et al., 2017). Nevertheless, the potential cost savings, increased productivity, soil health benefits, reduced input requirements, and environmental advantages make mulching a valuable practice with positive economic implications in various contexts (Choudhary and Bhambri, 2014).

3 Conclusion and future direction

Dryland farming focuses on rainfed agriculture, requiring efficient water resource utilization and water-conserving technologies. Mulching, a water conservation practice, is used in arid land areas to preserve soil moisture, control temperature, and minimize evaporation rates. Plastic film mulch usage increased by 5.7% in 2012, while organic mulching minimizes soil deterioration and enhances soil nutrient levels. Mulching reduces soil water loss, erosion, weed growth, and competition for nutrients and water with nearby fields. Mulching is a crucial practice in dryland agriculture, as rising temperatures and erratic rainfall can impact crop yield and soil moisture preservation. It is necessary to maintain soil moisture and make the most use of water.

Mulching materials may decrease nitrate leaching, increase microbial activity, and enhance soil characteristics. They can be inorganic, organic, or unique materials. However, the ecology of the soil and the environment are adversely affected by plastic mulching. Research is also ongoing on new mulching materials, including textile, petroleum-based, and biodegradable options. There is a need for further research since mulches made from recycled paper may leak ink into soil surfaces. Comprehending the mechanics of water flow and the interplay between soil mulch and the plant-canopy interface is crucial for optimizing mulching methods in agricultural soil.

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