Bulletin of the National Research Centre

REVIEW

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Mulching as water-saving technique in dryland agriculture: review article

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Abstract

Agricultural water resources have been limited over the years due to global warming and irregular rainfall in the arid and semi-arid regions. To mitigate the water stress in agriculture, mulching has a crucial impact as a water-saving technique in rain-fed crop cultivation. It is important mainly for preserving soil moisture, relegating soil temperature, and limiting soil evaporation, which affects the crop yield. Mulching has many strategic effects on soil ecosystem, crop growth, and climate. Mulch insulates the soil, helping to provide a buffer from cold and hot temperatures that have a crucial activity in creating beautiful and protected landscapes. This study has accumulated a series of information about both organic and plastic mulch materials and its applicability on crop cultivation. Moreover, future research potentials of mulching with modeling were discussed to quantify water loss in agriculture.

Keywords: Mulch, Soil-water conservation, Crop cultivation

Introduction

Agriculture is the largest water consumer in the world which accounts for 70% of total use (Qin et al. 2018). Among them, 80% of worldwide cropland is covered by rain-fed (non-irrigated) that produces 60–70% of the world's food (Chen et al. 2018). Considering the growing water shortage, rain-fed cultivation plays a prime interest in the worldwide food supply (Sun et al. 2012; Li et al. 2017). On the other hand, global warming and irregular rainfall patterns are responsible for the shortage of water resources which limit agricultural production in arid and semi-arid regions (Qin et al. 2015; Li et al. 2017). Thus, agriculture water management is a major concern to save water in cultivated land. Also, rain-fed cultivation in dryland farming is being pressured which required more effective utilization by using water-saving technologies (Qin et al. 2013). Therefore, conservative and efficient water-use has been practiced for many years in arid and semi-arid regions of the world with great success. The goal of all the water conservation systems is to maximize yield by minimizing water use. The efficient use of water is crucial factor during crop growth periods which can greatly improve yield. Therefore, conservation of soil moisture by using mulching may be an efficient option to save water as well as rising production in dryland farming. The interactions between mulching practices and conservation agriculture with global climatic environments are illustrated in Fig. 1. Mulching technique establishes a linkage between soil and agrometeorology which can modify the crop-growing environment.

Mulch is defined as a coating material spread over the soil surface (Kasirajan and Ngouajio 2012). Mulching is the technique of covering of the soil surface around the plants with an organic or synthetic mulch to create favorable conditions for the plant growth and proficient crop production (Chakraborty et al. 2008; Kader et al. 2017a). It insulates soil to protect organisms and plant roots from different meteorological conditions.

Mulching helps to improve crop growth as well as yield and at the same time it optimizes water use (Yu et al. 2018). There are two types of mulches: organic or biodegradable made of organic materials and inorganic mainly made of plastic-based materials (Kader et al. 2017a). These both are being popularized in recent years (Adhikari et al. 2016). Although it is still contradictory which one is best in agriculture; and research is still going on. In splash rainfall areas, plastic film mulching has been applied by ridge-furrow or raised bed system

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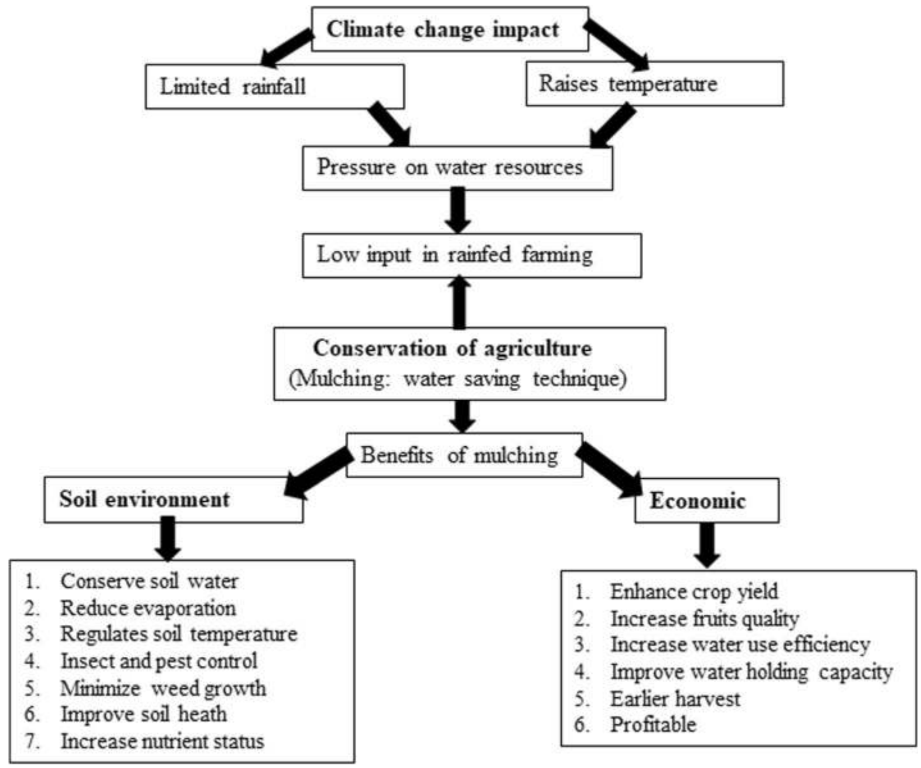

Fig. 1 Schematic diagram of the conservation agriculture interacts with climate and crop

for harvest rainwater (Gan et al. 2013; Li et al. 2017). This ridge-furrow mulching system is very popular in Losses Plateau area of China for successful cultivation of dryland crops like maize, wheat, potato, and cotton (Zhao et al. 2014; Yu et al. 2018). Moreover, erosion control is one of the important functions of mulch which is accomplished by the application of vegetative matter, such as grass, leaves, and prunings (Gyssels et al. 2005; Adekalu et al. 2007). The application of mulch can be classified as an effective soil conservation practice (Patil Shirish et al. 2013). Therefore, it is proven that the application of various organic and plastic mulches has an effect on crop production and soil hydrothermal environment in different climatic location under rain-fed conditions (Yang et al. 2012; Adeboye et al. 2017). Now, it is important to know the effectiveness of mulching which is equally useful and essential for soil and water conservation practices in the rainfed areas.

Facts and figure of plastic mulching

The use of plastics as mulching in agriculture is called plasticulture (Kader et al. 2017b) which is being used increasingly for producing fresh vegetables (Ibarra-Jiménez et al. 2011; Kasirajan and Ngouajio 2012). In every year, around 1 million ton of plastic film mulch is used worldwide (Yu et al. 2018). For example, in 2012, more than 60,000 ha of greenhouses used plastic film mulching in Spain which was annually increased by 5.7% (Transparency Market Research, 2016). China is the topmost user of plastic mulching estimated 0.7 million ton which accounts 40% of the world use (Daryanto et al. 2017). In recent years, China, Japan, and South Korea are the greatest users of plastic film mulch, which accounts for 80% of worldwide use (Ihuoma and Madramootoo 2017). In China, plastic mulching has enhanced wheat and maize production by 33.2% and 33.7%, respectively (Chen et al. 2014).

Water saved by mulching

Mulching is a water-saving technique in dryland areas for conserving soil moisture, regulating temperature, and reducing soil evaporation (Yang et al. 2015; Kader et al. 2017a). Surface mulching is widely practiced as water conservation technique in rain-fed farming systems (Chakraborty et al. 2008; Zribi et al. 2015). Plastic sheet mulch is more effective for conservation of soil water than that of wheat straw mulch (Li et al. 2013). The main strength of mulching is to conserve soil moisture by reducing surface evaporation and controlling soil erosion (Qin et al. 2016). Basically, mulching conserves soil water by reducing soil evaporation and regulating soil temperature which decreases irrigation demand during crop cultivation periods (Kader et al. 2017b). Soil water and heat transfer mechanism under the mulching is important to increase the availability of the system for efficient use of mulching (Li et al. 2018; Kader et al. 2019). It is still unknown in what amount of water saved by mulching which is critical due to interaction of microclimate, soil environment, and plant growths (Steinmetz et al. 2016).

Benefits of mulching

Mulching improves soil aeration around the plant, aggregates the soil particles, soil fertility, and drainage over time (Kader et al. 2017a). Mulch insulates soil helping to provide a buffer from heat and cold temperatures. The applications of mulch in crop field have a lot of benefits. The benefits of mulching compared with no-mulching in agriculture are illustrated in Fig. 2.

The important uses of mulching are reduction of soil-water loss, soil erosion, impact of water droplets hitting the soil surface, weed growth, and competition for water and nutrients from the surrounding fields (Tarara 2000; Yang et al. 2015; Kader et al. 2017a). Mulches prevent the water loss from soil evaporation which is very helpful during the summer season. Mulch can help to improve soil structure and nutrient cycling due to earthworm movement into the soil (Qin et al. 2015). It also lowers soil pH which enhances nutrients availability. Organic mulch decays over time and adds nutrients to the soil as it breaks down; it increases long-term nutrient availability in the soil (Larentzaki et al. 2008). Plastic mulch acts as impervious to the gaseous flow which is a superior barrier for the fumigants and solarization process. It can also play a surprising role in pest control and soil health (Chalker-Scott 2007). Thus, it helps in keeping the nutrient in plant root zone for efficient utilization of nutrient and reducing the fertilizer leaching. Mulch is also more esthetically pleasant as it creates a uniform look all over the landscape. The soil is a complex ecosystem, where the soil water is affected by many factors like crop, water absorption, soil and plant water evaporation, and infiltration of rainfall (Li et al. 2013; Chen et al. 2018). Moreover, the suitability of soil moisture and temperature for crops is changing in different growing stages. Organic mulching degrades to the soil that enhances organic matter consequently increases the water holding capacity of the soil (Kader et al. 2017c).

Suitability of mulching

Mulch can be used in fields before and after crop plantation as well as around the young plants. It is especially useful for high-value vegetable crops, and for growing crops in dry areas, during dry season cropping and in places where the soil is easily eroded by heavy rains (Larentzaki et al. 2008; Li et al. 2013). The use of plastic film mulch in agriculture is generally recommended for profitable row crops. Use of plastic mulch has the advantages of being lightweight, easy handling, and better

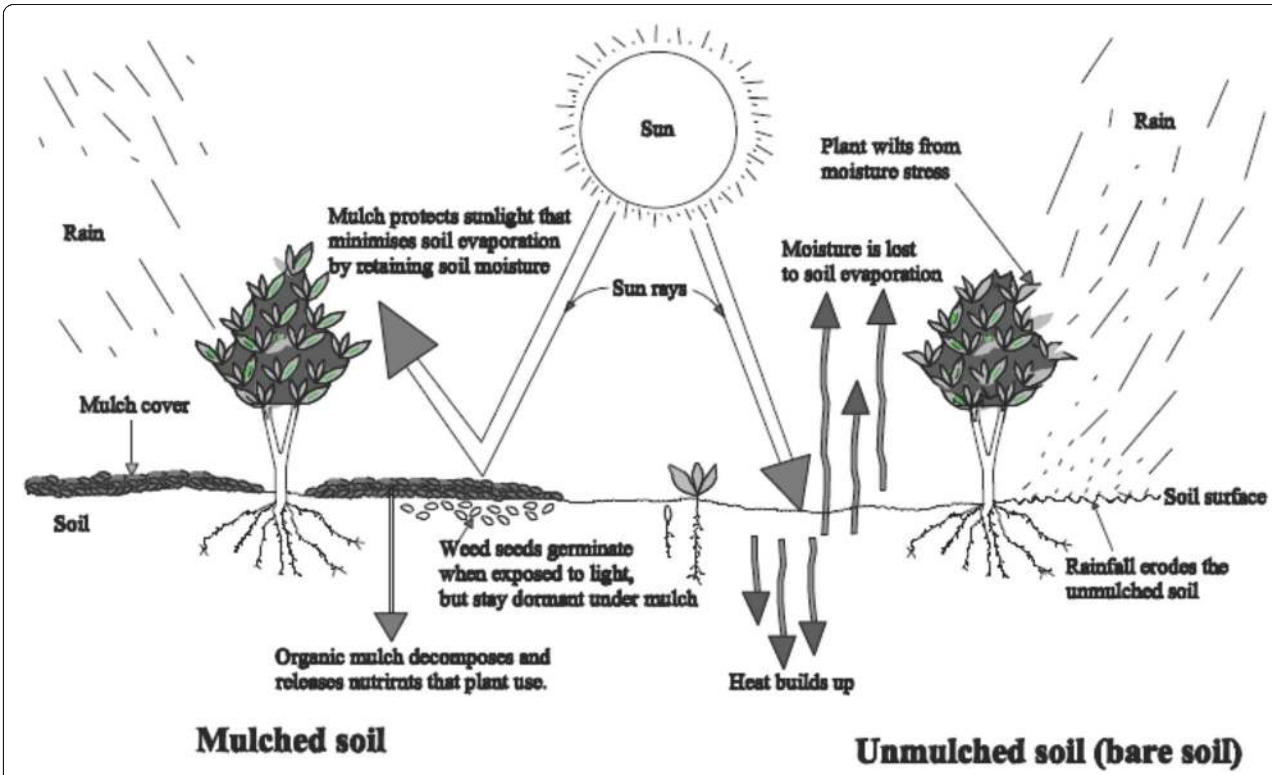

Fig. 2 Advantage of mulched and un-mulched soil interactions with plant and environments (Kader et al. 2017a)

coverage compared to organic mulch (Haapala et al. 2014). Excessive application of mulch to the field may adverse effects on pathogen and contaminants of soil. Thus, the recommended rate of organic mulching generally varies 4 to 8 cm in depth (ISA 2005) and for plastic mulching is 15 μm. Nowadays, researchers are exploring new types of mulching materials like biodegradable and petroleum-based mulch (Adhikari et al. 2016). But, most biodegradable mulches do not have any additional advantages in terms of crop production over plastic mulch (Adhikari et al. 2016; Moreno et al. 2017). With these limitations, biodegradable mulch is still far from wide adaptation for crop production. However, the suitability of mulch is highly characterized by types of crops, and climatic environment, therefore comprehensive field trials are crucial with various organic and plastic materials.

Selections of mulching

In broad, the choice of selection of an appropriate mulching material depends on the types of materials, ecological locations, colors, thickness, perforations and availability of materials, cost-effectiveness, and feasibility of the crop (Wang et al. 2015). The comparative attributes of the selection of organic and plastic mulching are discussed in Table 1.

Negative impacts of mulching

Mulch can be expensive in terms of labor, transport, setting removal, and disposal. The plastic film has intimate contact with soil which creates fragment and contaminants to soil (Steinmetz et al. 2016). Many types of organic mulching such as grass and straw contain seeds that may allow to grow weeds and release acid to soil (Chalker-Scott 2007; Patil Shirish et al. 2013). Moreover, organic mulch material especially newspaper is affected by wind. Constant moisture content, higher temperature, and better aeration of the soil tend to favor higher microbial biomass in the soil thus ensure more complete nitrification under mulched soil (Huang et al. 2008). Soils are heavily contaminated with the films which are disposed by farmers through on-site landfilling and burning (Gonzalez-dugo et al. 2014). The plastic film fragments are discarded and buried in the arable layer which retards crop growth.

Future research

Farmers in developing countries are unaware of environmental contamination of plastic mulching. Plastic mulch has negative impact on environment and soil ecosystem, thus finding new mulching materials is crucial. Mulch derives from plant sources can be a beginning of the lifecycle as a renewable source. There is still research limitation of economic analysis for newly developed biodegradable, textile, and petroleum-based mulch materials for conserving agricultural water resources. Moreover, the recycle paper-based mulch such as newspaper releases ink to soil surface (Haapala et al. 2014) which causes physicochemical interactions with soils required

Table 1 Comparison of various characteristics between organic and plastic mulching

Subject	Organic mulching	Plastic mulching
Materials type	Bio-based cellulose, chips, leaf, paper	Acetate, polyethylene, polymeric material
Durability	Temporary and decay over time	Long-lasting, 2–3 crop seasons
Thickness	3–5 cm, controlled by application rates	15–20 μm; 15 μm is most effective
Colors	Natural	Black, silver, white, red, blue, yellow, etc.
Weed control	Effective but grass material grows weed	High weed competition except the transparent color
Solarization	Not effective in most of the cases	Most effective by boosting soil temperature
Pest management	Reduces thrips and fungal disease	Reduces thrips, spider mites, and whiteflies
Fragments	Degradable to soil	Problematic and contaminated after 1-2 seasons
Availability	Locally available	Not locally available
Priority mulch	Straw (rice and wheat)	Black plastic
Costing	Cheap	Expensive
Labor	Not laborious	Laborious during setting and removing
Degradability	Naturally decompose and add nutrients	Discarded and buried that polluted soil
Plant growth	Moderate growth	Fast growth and earlier harvesting
Water infiltration	Increases	Restricts water flow

deep investigation in future. Further studies including suitable mulching application rates and plant response are required. Prospective research works may also concern about cost-effectiveness of hydro-mulching, sprayable mulch, biodegradable, bio-film, and petroleum-based mulching in agriculture.

Modeling approach of various mulching materials may need to concern for efficient use and availability of the system. Organic mulching protects direct rainfall infiltration and plastic mulching restricts water flow to the soil profile. Therefore, the water flow mechanism of both organic and plastic mulch shows different characteristics which need a modeling approach. For example, the modeling effects of water vapor flow and heat transfer process through various thickness organic mulched soil in response to crop growth in different climatic regions may have attention in future research (Kader et al. 2019). Moreover, different plastic colors of mulching show different optical properties thus mulch color may influence soil temperature and canopy distribution of plant. Therefore, the numerical model is required to focus the interactions among soil, mulch and plant canopy interface. It may create new window to future opportunity for efficient use of mulching system in the agricultural soil. The interactive effects of soil water in terms of soil heat capacity and thermal conductivity under mulching soil need to be modeled in the future.

Conclusion

Mulching has become an important water conservation practice in modern agricultural production in arid and semi-arid environments. The mulch material protect soil surface from sunlight which reduces evaporation by preserving soil water and altering soil temperature. The utilization of water within soil root zone is a crucial phenomenon to increase water use efficiently and save the water resources by mulching. Moreover, mulching is not only a water-saving technique but also responsible for the beautification of farmlands. The selection of mulch materials largely depends on availability of material, climate, durability, and cost-effectiveness. It also needs to be environmentally viable for sustainable use. Therefore, it is concluded that the various mulching material uses can save the water resources in agriculture which lead to improve crop yield in rain-fed cultivation.

Acknowledgements
The authors thank the anonymous reviewers for providing constructive comments and suggestions.

Author's contributions
MAK contributed to the conceptualization and analysis, and wrote the paper. AS, AMB, AJ, NIK, and FHK reviewed, edited, and proofread the paper. All authors read and approved the final manuscript.

Funding
This research has not received any funding.

Availability of data and materials
All data generated or analyzed during this study are included in this published article.

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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Received: 26 March 2019 Accepted: 30 August 2019
Published online: 10 October 2019

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