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An Approach of Water Conservation in Agriculture By Mulching, in Arid and Semi-Arid Regions of Rajasthan, India

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ABSTRACT

Water is one of the most important inputs essential for the agricultural practices. Most arid and semi-arid areas have insufficient and unreliable rainfall pattern. Also, a high rate of evaporation, loss of run off water and soil infertility is big problem. Under these climatic conditions the most important targets are to improve soil and water conservation and efficient use of rain water. Under these circumstances it is essential to understand and find new ways and techniques to preserve and conserve the water resources. Application of mulching to agricultural land can mitigates these problems. Mulching possess positive impact on soil by improving rainfall acceptance by enhancement of soil structure and reducing erosion along with additional benefits of increasing soil microorganisms, soil nutrients and thus improved crop growth. This study discusses the importance of both inorganic and organic mulches and its applicability under arid and semi-arid conditions. The paper focuses and highlights the recent research progress on various types of mulching to use to conserve soil water in agricultural practices especially in arid and semi-arid climatic conditions.

Keywords Conservation, Infilteration, Mulching, Runoff, Water.

INTRODUCTION

Rajasthan is the largest state in India covering an area of 34.22 million hectares, i.e., 10.5% of the country's geographical area, but sharing only 1.15% of its water resources. The state is predominantly agrarian as the livelihood of 70% of its people depends on agriculture-based activities. In the last 50 years, a threefold increase in the human population and a doubling of the livestock populations have put tremendous pressure on the fragile water and land resources of Rajasthan. Water scarcity problem becomes further complex in arid and semi-arid regions. Most of the state (60—75%) is arid or semi-arid. The arid and semi-arid regions are usually with low and erratic rainfall, high summer temperature, low humidity and high-velocity wind causing an average potential evapotranspiration of 2,000 mm, a negative water balance and acute water deficit. Further, enhanced global warming and uneven rainfall patterns are responsible for the scarcity of water resources which check the agricultural production in arid and semi-arid regions (Li et al. 2017). The farmers use excess quantity of fertilizers and pesticides so to increase the crop production but these also causes threats on soil health. Also, over irrigation of farmland is causing the problems of soil erosion and salinity. Therefore, the

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available surface water and ground water resource has to be properly managed by using water optimally in every sector of water use, mainly of agriculture sector. Also, rain-fed agriculture in dryland areas is being forced which required more effective utilization and management technologies to save water (Qin et al. 2015). Characteristically soils of these regions are very low in organic matter / humus and most of the nutrients reserve is present in un-weathered mineral forms. These soils have low clay and silt and therefore nutrient adsorption and retention by these soils are very low (Kumar et al. 2009). To mitigate the water stress and poor physico-biological characteristics of soil in agriculture ; mulching has pivotal impact as a water conserving technique in rain-fed crop cultivation as well as in dry agricultural lands. The goal of all the water conservation systems by mulching is to maximize yield by minimizing water use. Mulching is the process or practice of covering the soil / ground to make more favorable conditions for plant growth, development and efficient crop production (Sharma and Bhardwaj 2017). Mulching rises in water holding capacity, conserve the moisture of soil, prevents the soil erosion, modest the soil temperature, supply nutrients to the plants by composting slowly in soil, and also enhances the beneficial microbial activity and helps in fighting pathogens and pests (Kader et al. 2019a).

Mulching is one of the fastest growing soil water conserving applications in agriculture in the world. It is actually a boon to dry-land farmers which is bringing a revolution in agricultural water management. Various National and International research work (India, China, Egypt, Spain, South Africa) and studies have been reviewed to analyze the potential effect of mulching practice in agriculture in arid and semi-arid regions for the water conservation. These studies have revealed that definitely application of this approach can be milestone in agriculture in dry lands of Rajasthan, India.

Mulch and their types

Mulch is English word which is probably derived from the German word 'molsch' which means soft, beginning to decay (Jack et al. 1955). Initially, it was referred to early gardener's use of straw, leaves and loose earth spread on the ground to protect the roots of newly planted trees and shrubs. Mulch is often defined as any material applied to the soil surface as cover. It can be divided into two general groups-organic or biodegradable mulch made of organic materials and inorganic or non-biodegradable mulch mainly made of plastic-based materials. Organic mulches such as compost, bark, wood chips, leaves, seed hulls, grass clippings, nut shells, newspaper, cardboard, or straw have the added benefit that they furnish the nutrients to the soil as they decompose. This type of mulch needs to be periodically reapplied. Inorganic mulches such as gravel, black plastic, or fabric perform many of the same functions as organic mulch but do not add organic matter to the soil. There are also living mulches such as clover and ground covers that cam be used to over winter garden beds or when other types of mulch are not desired (Fig. 1).

Mulches are used for various reasons in agriculture but in perspective of particular arid and semi-arid regions of Rajasthan the most important objectives is soil erosion control and water conservation. This environment friendly technique may emerge as sustainable agriculture model in these regions.

Mulching and water conservation

Mulching aid in agriculture is very old and ancient practice for conservation of water. It minimizes water vapour loss, reduces soil erosion, overcomes weed problems and also reduces nutrient loss (Van Derwerkenand and Wilcox 1988). In addition, mulching also improves nutrient status of the soil and thus increases the growth, canopy and yield of the crops (Kumar et al. 1990).

Mulching conserve the water by threes ways in agriculture ; (i) reducing the evaporation of soil water (ii) available the deep soil water to the plant root to support and enhance the shoot biomass and (iii) optimize the dry matter allocation by selectively increasing the reproduction (Li and Zhao 1997, Li et al. 2000). Soil water content depends not only on precipitation and irrigation, but also on temperature, evaporation and soil structure (Haapala et al. 2014). Mia et al. (2020) revealed that along with soil water conservation mulching is also excellent practice for

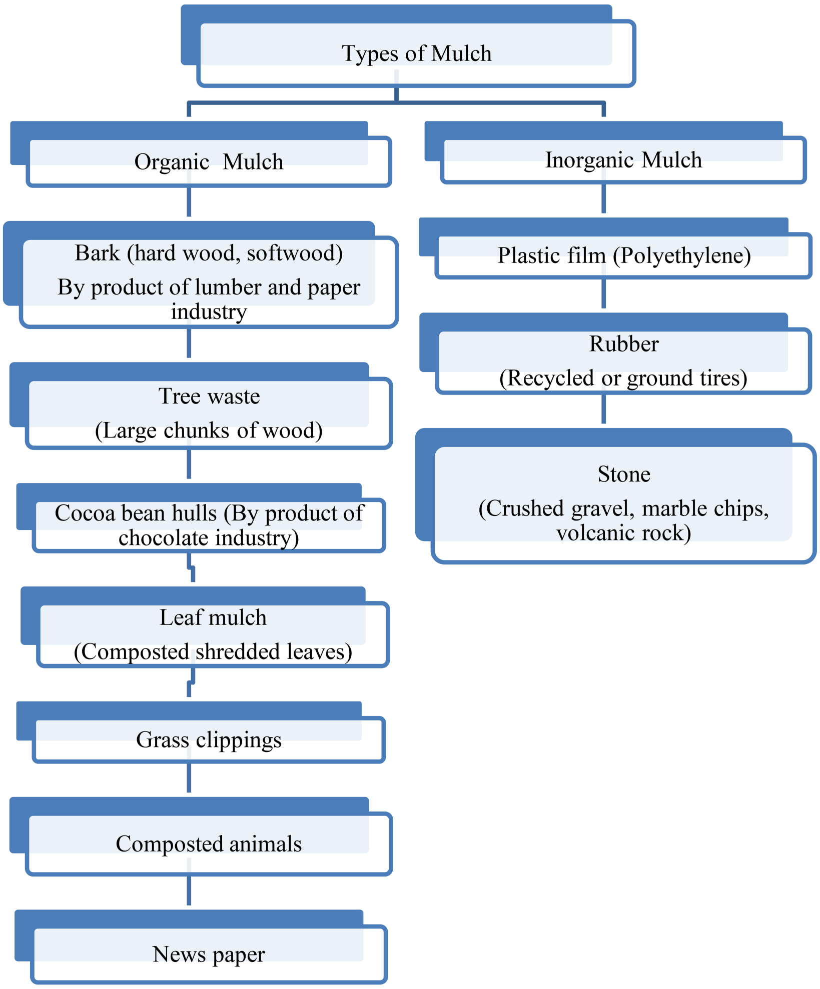

Fig. 1. Types of mulching

weed suppression in sustainable agricultural systems.

Zhao et al. (1995) have suggested that conservation of water by better utilization of soil water is the best way to increase crop yield in arid and semiarid areas. Soils from dry region are highly susceptible to water erosion and wind erosion because rainfall occurrence is frequent during intense storms and surface is not adequately protected by vegetation which effectively retards runoff. Therefore, to reduce erosions by wind and water is an important reason for using mulches in dry regions. Mulch amendment soils not only reduces run-off and but also decilines the soil erosion (Tyagi et al. 2017). Slingerland and Masdewel (1996) conducted experiment in Tagalla in the Sudano-sahelian zone of Burkina Faso and reported that the runoff from the mulched plots was on average only 35% (the range was 8.51%) in compare to the runoff from non-mulched plots during the entire growing season. Likewise, Adeboye et al. (2017) reported 17% increase in soil water storage in the upper 30 cm of the soil with mulch in Ile-life, Nigeria. Mulching with various organic and inorganic amendments conserve an average of 35% more soil water content over approximately six weeks of null irrigation than plants with any mulch (Stelli et al. 2018).

Donjadee and Tingsanchali (2016) experimented with rice straw mulch (RC) and vetiver grass clippings mulch (VGM) on an agricultural area and reported that at the rainfall intensity of 65 mm/h and mulch rate of 1.5 t/ha, RC reduced runoff and soil loss less than VGM but for higher mulch rates, RC performed better than VGM. RC Mulch rate at 5.0 t/ha, reduced runoff and soil loss by about 47.5% and 62.9%, respectively, whereas, VGM at the same rate showed corresponding reduction by 42.4% and 53.7%, respectively. On the basis of different behavior of these mulches they suggested most suitable application rate, 5.0 t/ha for RC and 7.5 t/ha for VGM, for soil and water conservation. Singh et al. (2016) while working for irrigation of wheat crop at Ludhiana, Punjab, reported that with irrigation at 50% soil water shortage, rice-straw mulch reduced the number of irrigations, about 50 mm for sandy loam and 60 mm for clay loam. The reduction in irrigation amount was attributed to reduced soil evaporation. Mulch reduced irrigation requirement more for the sandy loam than the clay loam soil. Likewise, experiment was performed by Rahma et al. (2019) at Loess Plateau, China. The reported that for short slopes (1 m), the optimal straw mulch rate of 0.4 kg/m is efficient to save the water for a silt loam and a clay loam soil. In case of a clay loam soil the mulch rate of 0.4 kg/m would be optimal only under the 90 mm/h rainfall that is 0.8 kg/m would be required for the 180 mm/h rainfall.

Increase in the soil water storage was also revealed by Xiaomin et al. (2017). They designed mulching experiment with wheat straw, white polythene film and black polythene film. the white and black polythene film treatments were found more efficient in soil water storage than the straw mulch. The soil volumetric water content ranged between 0.15 and 0.24 g/cm^3 and was found higher toward the top and the base of the profile and least in middle of the soil profile. An experiment performed by Almetwally et al. (2019) at Egypt reported increased water retension in sandy soil along with crop yield by mulching the rice or wheat straw to soil by 30% v/v. Also, the use of cellulose extracted from agricultural residues showed an improvement in soil water retension properties by adding an optimal cellulose ratio of 2% w/w. In central Japan straw mulching was applied at rain-fed soybean by Kader et al. (2019b). They found that 0-3 cm straw mulch layer contributes 16–96% vapour to the total water flow and released 0.0322 to 0.0295 MJ/m heat per day. Water balance in the mulched soybean farm land reported that the straw mulch layer enhanced the rain water infiltration by restricting the evaporation from the soil surface. Under drought conditions rice straw organic mulching was merged with pulse drip irrigation at the research farm station of National Research Center at Al-Nubariya Region, Al-Buhayrah Governorate, Egypt (Abdelraouf et al. 2019). They observed increased size of the wet soil within the root zone, thus decreasing the stress of water on the roots of the orange trees. Application of rice straw cover at a rate 9 t/ha possess positive impact on crop yield, this could be due to a lowering of evaporation rate and minimizing the salt accumulation in the root zone compared with non-mulching. In the study at North-western China Yin et al. (2019) reported reduced soil evaporation by 9.0–17.3% with treatment no tillage with plastic and straw mulching and the proportion of evaporation to evapotranspiration by 8.6–17.5% compared to conventional tillage without any mulching. In mulching practice at agricultural tillage areas, straw mulch is strongly recommended by Li et at. (2020). They also suggested 6–8 Mg/ha as a reference mulch application rate for organic mulching.

Effectiveness of elephant grass (*Pennisetumpurpureum*) as mulching material was studied by Adekalu et al. (2007) in agricultural soils at South Western Nigeria. They observed decline in water runoff and soil loss, with the increased rate of mulch and slope. Surface runoff, infiltration and soil loss was found in high correlations (R=0.90, 0.89 and 0.86, respectively) with slope and mulch cover. They also reported increased stored soil water and that can be used during dry weather.

Polyethylene is among the most used synthetic polymers in mulching applications. Li et al. (2001) reported that black polyethylene mulch maintains high soil water contents than the un-mulched field. The plastic film mulch was reported for increased root growth by Kwabiah (2004). He found that under the plastic film more roots were distributed in mid-soil profile and deep-soil profile, this crop can absorb water from the deep-soil profile and this resulted to the increased plant growth and yield. Usefulness and beneficial use of plastic mulch at water scarce region of Minqin County was studied by Ingman et al. (2015). Through interview and survey of farmers they reported that 87% of Chinese farmers are using plastic mulch to conserve water and 53% to increase yields. They also indicated that farmers perceived water savings of 24–26% when used plastic mulch. Zhang et al. (2017) studied the plastic-film mulching at maize fields in semiarid regions of China. They reported that topsoil temperature (5–25 cm) was higher in field amended with plastic film mulch than the control and this resulted in greater accumulation of water in soil (0–200 cm) up to 40 days after planting. At the rain-fed agriculture in North-western China Ma et al. (2018) found increased soil water content by 9.0% with plastic film mulching compared with non-mulch cultivation field. This effect was observed decreased with increasing soil depth. Soil water content at 0–20 cm depth was increased by 12.9% whereas at 80–100 cm depth soil water content was found decreased (only 6.1%).

Main problem of plastic mulches are they are non-degradable and after the use it form the harmful residue in the field which needs to be removed. Burning of the plastic mulch produces the harmful gas in the air and causes air pollution. If disposed as such on the landfills ; it obstructs the infiltration and percolation of water in ground. In order to avoid these problems biodegradable plastic mulches, offer better alternatives as an environmentally sustainable technique to conventional polyethylene mulch (Ahirwar et al. 2019). Chen et al. (2019) reported plastic film mulching along with drip irrigation as an important agricultural practice to conserve soil water and for increased productivity of crop, worldwide. They suggested that biodegradable film mulching can be a valuable alternative to plastic mulching. For this purpose, natural filler (residues of agricultural practices) has been extensively reported. The advantages of this type of filler are their low cost, biodegradability, low abrasiveness for the thermoplastic processing equipment, besides being non-toxic. Among the natural fillers, lignocellulosics (derived from wood or plants and are mainly composed of cellulose, hemicellulose and lignin) are usually used. Poly (butylene adipate coterephthalate) (PBAT) is one of such biodegradable material that have been used as the basis for producing mulch films to replace conventional plastic such as polyethylene. De Oliveira et al. (2019) develop PBAT films containing carnauba wax and sugarcane residue for mulching applications. Carnauba wax was used as additive to reduce the water vapour permeability of polymeric films. Likewise, work was also reported by Rodrigues et al. (2014). They prepared composites from cassava starch, cashew tree gum and carnauba wax and reported that carnauba wax promotes a decrease in the water vapour permeability of the composites. Chiumarelli and Hubinger (2014) produced edible films for food coating and the results showed that the formulation containing 3% cassava starch, 1.5% glycerol 0.2% carnauba wax and 0.8% stearic acid has better moisture barrier and gas exchange (CO_2 and O_2) properties.

Sprayable biodegradable polymeric mulch film is emerging as a promising next generation environment friendly alternative to non-degradable low density polyethylene (Adhikari et al. 2016, Braunack et al. 2020). Memon et al. (2017) postulated Ridge Furrows Plastic Mulching (RFPM) method based on the ridges cover with plastic sheet to increase the soil water infiltration and water availability to the crop helps to boost soil diversification and benefits the environment. With this type of mulching Liu et al. (2018) revealed increased soil water storage from 0-40, and straw mulch slightly increased soil water storage from 0-60 cm compared with without-mulched plots of winter wheat at the Loess Plateau.

In recent years, the various new mulches have been introduced as an alternative to plastic mulches. Farzi et al. (2017) reported many organic mulches, such as Pistachio shell mulch (PSM), wheat straw mulch, de-oiled olive Pomace mulch (DOM) and wood chips mulch, to improve the water content of soil. Among these DOM and PSM were found best to maintain the optimum soil water content for farming the olive plant.

Compost mulch increases soil organic carbon which in turn increases plant available water. It was revealed that as the soil organic carbon (the carbon fraction of soil organic matter) increases by a factor of four, the plant available water increases by about

2.5 times (Hudson 1994). Organic mulching material made from the outer shell of the cocoa bean material breaks down slowly and will not disappear into the agricultural soil. Applying in the spring or summer will not only conserve water but also reduce weeds. Mulching with organic materials to soil cover increases the soil nutrients, maintains the optimal temperature of soil, prevents the soil erosion and restricts the rate of evaporation and weed growth. All these effects attribute improved soil health. Organic mulches are also cheap materials and thus cost is also economical (Ranjan et al. 2017).

Bark-chips have been reported to improve water-holding capacity of the soil, reduce weed growth and lower the soil temperature. These are widely available in a number of sizes and colors. Bark chips can decompose rapidly (within 1–2 years) and also remove the nutrients (such as nitrogen) from the soil during decomposition (Wiese 1999). Donk et al. (2011) evaluated that addition of mulch at any thicknesses can conserve the soil water content compared to when no mulch was used.

Paper as a mulching material has been applied as soil cover by various researchers. Matitschka (observed) that lettuce (*Lactuca sativa* L.) plot without mulch on the soil dried faster than was covered with black paper or plastic mulch. Oiled paper mulch has reported for improved efficiency to conserve soil moisture. Untreated paper was found more permeable to moisture than oiled papers that have accelerated moisture losses due to rapid decomposition (Schonbeck and Evanylo 1998). Anderson et al. (1995) showed that oil-paper mulch reduced water evaporation than the untreated paper. They embossed that black poly-ethylene mulch was most efficient in reducing water evaporation. In Canada, Zhang et al. (2008) determined that both a biodegradable mulch paper and brown Craft paper could keep the soil moist than the plastic mulch. In contrast, J earlier it was shown that showed polyethylene more effective than paper mulches to conserve soil moisture in lettuce crops during dry periods.

In the arid regions with limited rainfall, a main barrier for dryland farming, a volcanic (pyroclastic) material "basaltic tephra" has been proved to be very effective for soil water conservation. Tephra mulching protects the soil surface by reducing the impact of raindrops, preventing sealing crust formation and reducing runoff of water, thus increase the water stock in the soils. This permits the irrigation-free agriculture in extremely arid and semi-arid environments (Tejedor et al. 2003). Othieno (1980) observed an increase of 16% soil moisture content in the uppermost centimeters of the soil while working with crushed volcanic rock (1.25 cm) in a region with rainfall of around 700 mm, but this percentage fell down to 1% at deep soil (30–40 cm). Chesworth et al. (1994) conducted a study in Ethiopia (annual rainfall of 755–723 mm) using mulch basaltic ash and pumice (grain size of 2–20 mm and layers of between 3 and 6 cm) and found that water content at 40 cm in the mulched soils was 10% higher than that the un-mulched soils. Basaltic ash mulch with a thickness of 6 cm was observed the most effective one. A pyroclastic mulch of 25 mm size was found effective in water conservation by Doolittle (1998). Tejedor et al. (2003) found the greater (approximately double) basic velocity with the tephra mulched soils than that of un-mulched soils, initial velocity was also reported much higher in the mulched soils (around 2.5 times greater), and the infiltration velocity in the mulched soils was reported fast and was observed slow in the unmulched soils. Tephra covering to soil surface offers greater permeability and protection to such soil and prevents direct action by the rain on the soil. They reported that in arid and semi-arid regions, inorganic mulches (volcanic materials-tephra) are very effective for soil-water conservation. The degree of effectiveness of mulch depends on the physical characteristics of the mulch (thickness), type of material and grain size. They observed that in the un-mulched soils runoff started only 3 min after the beginning of the rain, whereas in the mulched soil the runoff time occurred between 26 and 31 min after the beginning of the rain, depending on the tephra grain size. In the un-mulched soil, the rainfall lead to aggregates disruption, porefilling and formation of a surface sealing crust to the soil surface that reduces water infiltration (Valentin 1991, LeBissonais and Singer 1992). They concluded that a layer of basaltic tephra placed on the surface of soils has a great efficiency for soil water conservation in arid regions.

This type of mulching requires little inputs / efforts of energy, chemical and labor.

Gravel and sand mulching is a traditional technique, used for water conservation and has been practiced from ancient times. As a semi-permeable obstacles stone rows and live hedges improves the hydrological processes and soil fertility (Perez 1998). These mulches reduces evaporation and runoff, improves infiltration and soil temperation, limits wind and water erosion as well as enhances biological activity of soil (Li et al. 2001a, Li et al. 2001b, Li 2003).

Poesen and Lavee (1994) postulated that during rainfall, gravel-sand mulch first intercepts raindrops. This rainwater will then either be stored at the mulch surface, or absorbed deep in the mulch layer, or may evaporate, or lateral flow excess surface water as rock flow. Gravel mulch prevents soil surface sealing and crusting, and preserves the structure at the soil sulface, holds excess water in contact with the soil surface longer, and allows more infiltration (Adams 1966, Li et al. 2001b). A large pore of gravel allows rapid infiltration of water into the soil but retard evaporation. Water return to the atmosphere across the gravel pores in the vapor form. Therefore the gravel act as a one-way water valve for the soil and water remains in the soil for longer period and benefits growing plants (Fairbourn 1973).

Li (2000) reported the average evaporation rate for the pure gravel and pure sand mulch was 1.6 and 2.5 times higher, respectively, than for the uniformly mixed gravel and mulch ; 2.6 and 1.6 times lower than that for the without mulched-soil. He also reported higher soil moisture content in the gravel-sand mulched plots (72.6 mm) than the un-mulched field, particularly in the upper soil layer (20–60 cm depth), suggesting that surface gravel-sand mulch has high potential for soil-water conservation. Effects of permeable barriers stone rows and grass strips of *Andropogongayanus* Kunth cv Bisquamulatus (Hochst) and organic mineral sources was assessed by Zougmore et al. (2003). They found that stone rows provided more surface water storage and infiltration than the grass strips. Also, the arrangement of stone rows allowed reduced runoff velocity in compared to the barrier of grass strips. In the semiarid loess region of Northwest China cover of gravel-sand mulch at the soil surface was reported to affects the hydrological processes such as rainfall interception, runoff, infiltration and evaporation and dew deposition) Li 2003). He reported that among the 91 rainfall events, 18 produced a total runoff of 48.4 mm from the un-mulched field, while only 6 produced 3.4 mm runoff from the gravel-sand mulched field. This suggests that surface gravel-sand mulch can effectively reduce water runoff.

CONCLUSION

The arid and semi-arid area of Rajasthan suffers either from drought or from drowning. One of the practices that consume huge amount of water is over and excessive irrigation. Mulching the soil surface with a layer of organic and inorganic amendments is considered an effective method of conserving water in these regions. Application of mulch in farmland of such areas effectively reduces the irrigation requirements of plants by up to 70% by lowering the evaporation of water from exposed soil surfaces by providing shading to the soil. Mulch cover also acts as an insulator that keeps the roots of the plants at a constant temperature. The semi-arid area of Rajasthan with limited and erratic precipitation, dry climatic conditions, possess mainly sandy soil, mulched conditioners improve water retention and lateral root distribution in the soil, improves plant access to soil water, and reduces deep drainage of available water and thus reduces irrigation requirements. Mulching helps hold water and reduce leaching loss, and improves the drought resistance of plants. This is a significant benefit in non-irrigated areas.

However, certain non-degradable low density polyethylene mulches (LDPE) are of great matter of concern, although enhances crop water use efficiency and productivity but cause long term environmental pollution. Being persistent nature in soil, they have to be recovered and removed after successive crop yield which is not only difficult but also increases substantial cost to farmers and the environment. Due to increasingly stringent regulations regarding use of non-degradable plastic in agriculture they are likely to be phased out in the near future. Researchers have worked over it and have developed biodegradable mulch films (lignocellulosic fillers), of which, sprayable biodegradable polymeric mulch film is emerging as a promising next generation environmentally friendly alternative to LDPE. Despite all these attempts, scientists are still looking for new ways get the biodegradable mulch film that meet the criteria of high efficiency, easily implementable, cost-effective and environment friendly impact. Application of such amendments may increases little operational costs and further it is recommended that optimal levels of mulch, in order to prevent water losses, should be used according to the particular soil type, rainfall and other climatic conditions. This is one of the fastest growing soil water conserving applications in agriculture in the world. It is actually a boon to dry-land farmers which is bringing a revolution in agricultural water management. Practicing of mulching in arid and semi-arid regions of the Rajasthan will definitely-prove milestone in agriculture field.

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