



Significance of Mulching on Soil Conservation

K. Bhargavi ^{a*} and O. Anusha ^b

^a Department of Agronomy, Polytechnic of Agriculture, Punganur, ANGRAU, Andhra Pradesh, 517247, India.

^b Department of Agronomy, Polytechnic of Agriculture, Kalikiri, ANGRAU, Andhra Pradesh, 517234, India.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i203913

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/106902>

Review Article

Received: 24/07/2023

Accepted: 30/09/2023

Published: 09/10/2023

ABSTRACT

The rapidly expanding global population, coupled with limited accessible freshwater resources and recurrent climatic fluctuations, have placed significant stress on humanity. This pressure has necessitated decisive actions to curb water wastage. Concurrently, water conservation initiatives have gained momentum, particularly within the world's largest water-intensive sector, agriculture. One notable advancement in enhancing water use efficiency in agronomy is the widespread adoption of drip irrigation. This method involves the precise delivery of water directly to the root zone of crops, minimizing water losses up to 70% attributed to evaporation and distribution inefficiencies. Furthermore, the synergistic application of mulching in conjunction with drip irrigation in arid crop cultivation has emerged as a robust strategy for alleviating water stress in agriculture. Mulch, comprising natural, synthetic, or blended materials, serves as a protective layer between the soil and the atmosphere. Its multifaceted benefits include efficient soil moisture retention, regulation of soil temperature, prevention of nutrient leaching, improved fertilizer utilization, erosion resistance, weed suppression, and aesthetic enhancement of landscapes. This review paper comprehensively explores various facets of mulching, underscoring its role as a dynamic tool for water and soil management in agriculture while preserving the intrinsic value of cultivated crops.

*Corresponding author: E-mail: bhargavireddykoturi@gmail.com;

Keywords: Agriculture; agro-ecological system; mulching; water conservation.

1. INTRODUCTION

Enhancing soil moisture conservation remains a persistent objective within agricultural production, particularly in regions like India, where water resources are constrained and subject to regulation. The impetus for reducing water consumption in agriculture stems primarily from the escalating demands driven by the country's expanding population.

One such agricultural practice aimed at addressing this challenge is mulching. Mulching entails the application of a protective layer over the soil surface, which serves to curtail water loss through surface evaporation. Additionally, this layer exerts substantial weed control, thereby further optimizing water utilization efficiency in the field [1]. Applying agricultural by-products as mulching material represents a sustainable approach that not only conserves soil moisture and also improve crop yields. Abundant agricultural by-products such as wheat straw, grass clippings, and leaf debris, which are commonly generated by farmers, are currently expended as resources for disposal purposes [2].

The term "mulch" is derived from the German word "molsch," signifying materials that are soft and readily decomposable, traditionally referring to the practice of gardeners spreading straw and leaves on the ground as mulch. This age-old technique, encompassing the coverage of the soil surface with both organic and inorganic materials, has historical roots. Its utility spans the regulation of soil moisture, soil temperature, mitigation of nutrient losses, salinity control, soil erosion management, and enhancement of soil structure. However, in the context of modern agriculture, this practice has largely waned but is now experiencing a resurgence, notably within the framework of sustainable agriculture.

Extensive demonstrations have illustrated that various types of mulch can reduce soil erosion by over 90% compared to unmulched agricultural soil. The imperative to bolster food security while concurrently enhancing environmental quality has propelled the quest for materials capable of safeguarding soil integrity and promoting soil health [3].

1.1 Historical Development of Mulching

The practice of mulching has deep historical roots, characterized by the traditional method of

placing partially decomposed plant materials like straw, hay, sawdust, or discarded agricultural residues beneath plants. These traditional practices were typically applied on a small scale, especially in garden or nursery settings [4,5]

However, contemporary agricultural technology has ushered in a new era of mulching materials. These modern materials are typically manufactured in the form of extended polymeric sheets or textile fabrics, composed of either organic or inorganic materials. They are designed to cover extensive rows of plants in the field

The historical evolution of mulching practices can be traced back to the late 1930s when mulches were first introduced as materials capable of modifying the immediate surroundings of agricultural lands, horticultural parks, and forestry environments. The concept of deep mulching, employed for the protection of trees and shrub plantations against adverse conditions such as frost damage and freezing injuries in challenging ecological contexts, was first documented in 1941 [6].

2. SIGNIFICANCE OF MULCHING

2.1 Mulching to Improve Soil Health

Knowledge of the physical properties of soil is essential for defining and/or improving soil health to achieve optimal productivity for each soil/climatic condition. This envisages that for increasing crop production, soil physical properties must be maintained in order to ensure adequate crop growth, yield and development. Unless the soil's physical environment is maintained at its optimum level, the genetic yield potential of a crop cannot be realized even when all the other requirements are fulfilled. No doubt, if these soils are managed properly for good physical health, the yield potential of different crops can be increased significantly.

2.2 Moderation of Soil Temperature

"Mulching serves as an effective insulator, safeguarding the soil against both extreme heat and cold temperatures, which are primary factors constraining overall crop growth. Extreme temperature fluctuations can significantly hinder the development of plant roots by reducing nutrient and water uptake, ultimately subjecting

the plants to stressful conditions” [7,8]. “Therefore, the prudent management and regulation of soil temperature are paramount for optimizing plant growth. Studies have revealed that the application of mulch plays a pivotal role in regulating soil temperature, maintaining cooler conditions during scorching hot climates and providing warmth on chilly winter days”[9,10]. “The efficacy of temperature control via mulching is relative and influenced by its intrinsic characteristics. In the realm of mulch types, live mulch, despite its higher soil water consumption, exhibits the capacity to release more water vapor through the evapotranspiration process, thereby reducing soil surface temperature through its evaporative cooling effect when compared to non-living mulch materials” [11]. “Among inorganic solid-type mulches, gravel mulch has demonstrated superior temperature-regulating properties, surpassing materials such as concrete” [12,11].

Conversely, synthetic mulches have proven to be inefficient in temperature regulation, often elevating soil temperatures rather than maintaining them at desirable levels [13,14,15,11,8,16,10]. Similarly, hydrophobic natural mulches like pine bark have been observed to induce greater water loss through nearby leaves and elevate soil surface temperatures [17]. Thus, the careful selection of an appropriate mulch in consideration of local climatic conditions and its inherent characteristics is of paramount importance.

Ikeh et al [1] reported that the thickness of mulching material had significant influence in garden egg yield, weed growth and economic returns to management.

“In the case of plastic film mulching, soil temperature is markedly influenced by the color of the plastic mulch. Black plastic-film mulched plots consistently exhibit significantly lower soil temperatures (ranging from 1 to 2.80°C) in comparison to clear plastic-film mulched plots. This disparity arises because a substantial portion of the solar energy absorbed by black plastic-film mulch is dissipated into the atmosphere through radiation and forced convection”. Research by Anikwe et al. [18] further substantiates this, showing that unmulched plots consistently maintain lower soil temperatures (approximately 1-3.80°C lower) compared to plastic film mulched plots over various time intervals post-planting. Among various mulching techniques, plastic film

mulching, by altering the heat balance and consequently elevating soil temperature, has been observed to impact crop emergence positively [19].

2.3 Improve Water Retention Capacity of Soil

Organic mulches exhibit multifaceted characteristics, notably their darker hue, which results in reduced light reflection. This property leads to a decreased rate of evaporation when organic mulches are applied in agricultural settings, facilitating greater soil percolation and water retention [10]. However, it's important to note that inorganic mulches, particularly rocks, have a higher rate of light reflection, rendering them unsuitable for highly light-sensitive plants. Nonetheless, both organic and inorganic mulches outperform synthetic materials and control soil in terms of soil water conservation [20,21,22]. Commonly utilized mulch materials for retaining soil moisture include livestock waste, crop residues, and various types of stone gravels [23,24]. Arora S et al. [25] reported “that soil mulching not only increased the yield of chickpea and wheat but also improved the water use efficiency of these rainfed crops. Practices that reduce runoff and, hence, reduce sediment transport and improve water conservation include conservation tillage, mulches, cover crops, and chemical additives according to Unger PW, 2023”.

“In the context of soil water content management, black polyethylene mulch has been found to maintain significantly higher soil water levels compared to control (no mulch) and bare soil treatments” [26]. “Enhancing water use efficiency through optimized soil water utilization is a key strategy for increasing grain yields in semiarid regions” [27]. “Methods to achieve this efficiency include reducing soil water evaporation and tapping into deep soil water reserves to support biomass accumulation and optimize dry matter allocation, with a focus on increasing reproduction” [28].

Notably, plastic film mulch has been shown to promote root growth, leading to a greater distribution of roots in the mid and deep soil layers. This distribution allows plants to access water from deeper soil layers, ultimately boosting crop yields. Soil mulching not only increased the yield of chickpea and wheat but also improved the water use efficiency of these rainfed crops reported that soil mulching not only increased the

yield of chickpea and wheat but also improved the water use efficiency of these rainfed crops.

2.4 Soil Fertility Improvement

Organic mulches and biodegradable plastic mulches undergo decomposition within suitable environments, ultimately contributing to nutrient enrichment of the soil surface, enhancement of moisture retention capacity, and augmentation of the humus layer. However, the realization of these beneficial effects, their extent, and whether they occur at all are intricately influenced by the specific type of mulch employed, soil characteristics, and prevailing climatic conditions.

For instance, materials such as wood chips, straw, green manures, and bark mulches have been documented to yield higher nutrient contributions compared to inorganic mulches [29,30,31,32]. Ikeh & Akpan [16] study in southeastern Nigeria revealed that increase in organic mulching level, significantly improve garden egg yield. Live mulching such as using cowpea, groundnut or any other low grow crops had been reported to act as mulching material and equally add nutrients to the soil through leaf fall or nitrogen fixation. Nonetheless, it is noteworthy that Chalker-Scott [8] advocated for the cautious utilization of organic mulches in landscaping, cautioning against their excessive application in agricultural contexts. Despite their capacity to supply ample nutrients, their use on sensitive crops, living organisms, and water resources can lead to adverse consequences.

The decomposition of organic residues beneath plastic mulch introduces organic acids into the soil, resulting in a reduction in soil pH, which can subsequently enhance the bioavailability of micronutrients such as Mn, Zn, Cu, and Fe. This phenomenon has been substantiated by the observed increase in Fe and Zn content in soil beneath plastic mulch.

Zhang Y et al. [33] found that soil and water conservation measures increased the soil organic carbon, total nitrogen, microbial biomass carbon, and microbial biomass nitrogen by 8–57%, 1–14%, 25–68%, and 17–35%, respectively, with greater increases in the contour ridge cultivation tillage and straw mulching treatments and a smaller increase in the downslope ridge cultivation treatment.

Furthermore, the mineral N content (NO_3 and NH_4^+) in the soil tends to be elevated due to the

mineralization of organic N over time, thereby increasing the availability of soil nitrogen. As organic materials break down, they release soluble nutrients such as NO_3 , NH_4^+ , Ca^{2+} , Mg^{2+} , K^+ and fulvic acid into the soil, consequently augmenting soil nutrient availability beneath plastic mulch.

2.5 Improved Plant Establishment, Growth and Yield

Mulches serve as valuable tools to enhance the establishment of a wide array of woody and herbaceous species. They contribute to improved seed germination rates and enhance the survival of seeds, fostering robust root establishment, transplant survival, and overall plant growth. A key benefit of mulches lies in their capacity to enhance water retention, thereby allowing roots to extend and establish themselves more extensively beyond the trunk of the plant, ultimately promoting greater stability.

Notably, root development is most pronounced when organic mulches are employed, in contrast to plastic mulches or bare soil. Sheet and film mulches, in particular, promote root growth atop the mulch layer, which can lead to damage when the mulch is removed. The use of plastic mulches may result in increased mortality among transplanted material and inflict significant harm on delicate fine root systems. Conversely, roots tend to naturally grow into organic mulch layers, and this exploration of the mulch layer does not appear to harm the plant.

Plastic mulch application exerts a stimulatory effect on early crop emergence, thereby enhancing biomass production during the initial stages of crop growth. Li et al. [34] have reported that the use of plastic film mulching results in accelerated seedling emergence and earlier spike differentiation, contributing to the development of a greater number of spikelets and grains per spike in wheat. The amelioration of soil moisture levels and the elevation of topsoil temperatures achieved through plastic mulching led to an average reduction of 8 days in the time required for wheat seedlings to emerge. The results of the study had shown that irrigating garden egg field once in every two weeks with 1500 L/ha and application of 10 t/ha of organic mulch would guarantee dry season production of garden egg in the study area and also help to reduce high weed infestation which is one of the major threats to garden production in Okigwe southeastern Nigeria [16].

Plants subjected to mulching treatments exhibited an earlier transition into the maturation phase, accompanied by an extended maturation period. This temporal shift is conducive to partitioning assimilates for storage in vegetative organs, thereby facilitating the development of the reproductive organs of wheat plants. Consequently, the duration of the reproductive phase is extended, optimizing yield potential [35].

2.6 Suppress Water-Stealing Weeds

Mulching exerts inhibitory effects on both seed germination and weed proliferation by impeding the penetration of sunlight to the uppermost soil layer. Consequently, the presence of fewer or no weeds translates to reduced competition for vital resources, including water and nutrients, thereby promoting superior crop growth. Moreover, the absence of weeds simplifies maintenance efforts, facilitating enhanced crop development through improved soil aeration, enhanced drainage, and a reduction in soil erosion [36]. Downer & Hodel [32] have highlighted the competition introduced by cover crops for water resources in relation to the primary crop of interest, ultimately concluding that mulches offer greater advantages in this regard. The core objective of mulching is to deprive weeds of light and curtail their growth, as every type of mulch covers the soil surface and exerts physical pressure on weed development. Ikeh et al. [1] conducted an experiment on different types of mulches and results showed significant differences in all the weed infestation parameters, vegetative growth and yield parameters assessed. In both cropping seasons during 2016 & 2017, the control had significantly higher weed density and biomass compared to plots treated with different types of mulching material.

2.7 Soil Erosion Control

Mulching materials serve as a protective cover for exposed soil surfaces, effectively buffering against the direct impact of wind and rainfall, thereby mitigating soil erosion. This protective action contributes to an enrichment of soil nutrient content by preventing leaching, promoting the efficient utilization of fertilizers, and conserving soil nutrients. In hilly terrain, mulch materials can directly intercept and disperse the kinetic energy of rainfall, resulting in an elevated soil infiltration rate and the stabilization of slopes [8].

Moreover, mulch plays a crucial role in reducing soil compaction, which can occur due to the

weight-bearing load of heavy machinery and equipment, potentially detrimental to crop roots and overall plant growth. Timely mulching, as recommended by Donnelly & Shane [37], is essential to counteract soil compaction effectively, as it aids in preserving soil structure and aggregation.

The issue of soil compaction finds an effective resolution through the use of living mulch materials, such as grasses and bark, particularly on sloping surfaces. These living mulch materials exhibit the capacity to bind soil particles into a cohesive unit, as documented in studies by Sartz [38], Samarappuli & Yogaratnam [39], Oliveira & Merwin [40], and Tanavud et al. [41].

Empirical evidence from Borst & Woodburn [42] highlights that a mulch layer with a thickness of 0.6 inches can reduce soil erosion by approximately 86%. Similarly, the combination of straw mulch and erosion control nets has proven highly effective in curbing soil erosion, achieving a remarkable reduction of 95% compared to bare soil conditions, particularly in forested areas [43].

2.8 Mulches on Insect Pest and Disease Management

Polyethylene mulches have been employed with the aim of potentially mitigating the presence of insect and disease pests [44]. White yam mulched with leguminous crops that least severity of insect pest damage at harvest. The impact of mulches on the microclimate and energy balance of plants is contingent upon their ability to transmit, absorb, and reflect solar radiation [45,46]. Incorporating ultraviolet reflectance can disrupt the host-seeking behaviour of thrips, resulting in a reduction in thrips populations in the vicinity of host plants [47,48,49,50]. The utilization of highly ultraviolet-reflective aluminized mulch as a covering for planting beds serves to provide this crucial reflectance, effectively interrupting the initial flight patterns of thrips into a field [47,49,50].

2.9 Reduction of Salt and Pesticide Contamination

In arid landscapes, evaporating water leaves behind salt crusts. Because mulches reduce evaporation, water is left in the soil and salts are diluted. Organic mulches can actively accelerate soil desalinization and help degrade pesticides and other contaminants.

3. BIODEGRADABLE MULCHES

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3.1 Non-Biodegradable Film Mulches

Various polypropylene (PP) black films underwent comprehensive testing to evaluate their efficacy in weed control, and the outcomes revealed a noteworthy increase in plant height [51]. Typically, black and other film colours find application in the cultivation of crops like strawberries and watermelons, as these crops necessitate elevated soil temperatures to achieve optimal sweetness levels. Polara and Viradiya [52] presented compelling evidence of enhanced yield and quality attributes in watermelon crops grown on silver-black PE film. However, it is widely acknowledged that conventional PE films pose significant environmental concerns.

In light of these environmental considerations, Costa et al. [53] conducted a comparative study, pitting PE film against five biodegradable film alternatives. The research findings demonstrated no significant differences in the productivity and quality of strawberries, providing valuable insights into environmentally sustainable cultivation practices.

3.2 Mulching Advantages and Disadvantages

The influence of different mulch types on crop yield might be positive or negative, related to

their weed suppression effect. Many researchers proved the positive effects of mulching on crop growth and the obtained yield quantities and qualities [54]. Regardless of the colour, nonbiodegradable PP and PE film mulches proved to be the most efficient in preventing of germination of seeds of most weeds and their further growth, though they are also helpful in preventing loss of moisture from the soil and in balancing its temperature [55]. Their application frequently brings about many other benefits, such as reduction of run-offs, increase in rainwater penetration, control of erosion, correction of the chemical balance of the soil and reduction of pest and disease damages. However, they also have some environmental disadvantages, related to the removal and handling of their waste [56].

4. CONCLUSION

In today's era of globalization and increased awareness of health through organic agriculture, there is a growing global demand for horticultural crops of good quality. The application of mulch has played a significant role in enhancing soil properties such as temperature, moisture levels, bulk density, aggregate stability, and nutrient availability. Moreover, plastic mulching has proven to have a positive impact on plant growth and yield by modifying the microclimate of the soil. Despite its numerous advantages, there are challenges faced by farmers, including the high initial cost and the need to remove and dispose of plastic materials. To address these limitations, a viable solution is the adoption of photo and biodegradable plastic mulches. These eco-friendly alternatives not only sustain productivity but also contribute to environmental protection by reducing the pollution associated with traditional plastic usage.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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