Effect of mulching on soil and water conservation

Review Article

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.

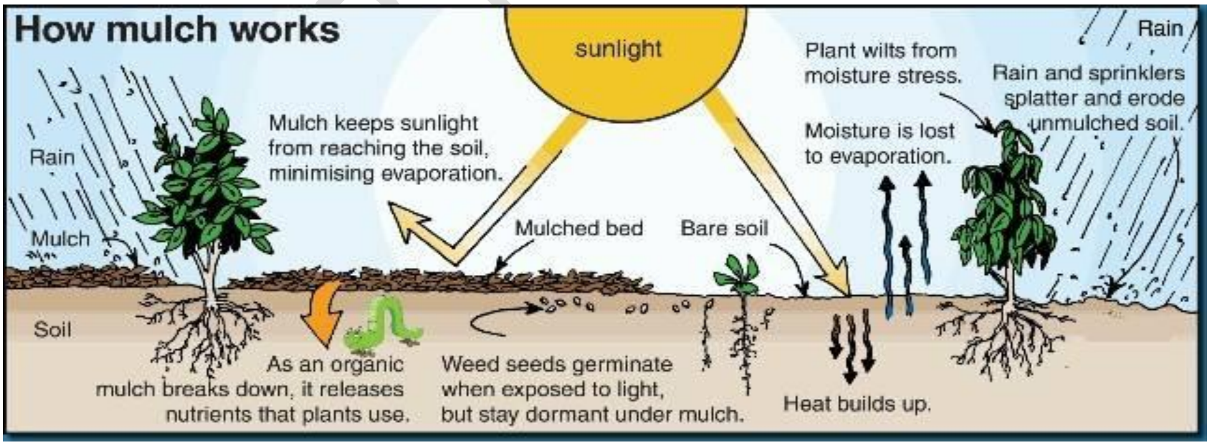
One notable advancement in enhancing water use efficiency in agronomy is the widespread adoption of drip irrigation. This method involves the precise delivery of water directly to the root zone of crops, minimizing water losses up to 70% attributed to evaporation and distribution inefficiencies.

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

Key words: agriculture, agro-ecological system, drip irrigation, mulching, water conservation

GRAPHICAL ABSTRACT



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. The urban populace's unvarying and escalating water requirements exert continuous pressure on the available water resources allocated to agricultural endeavours. Consequently, there exists an imperative to explore novel methodologies to ameliorate soil moisture retention.

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. Employing agricultural byproducts as mulch represents a sustainable approach that not only conserves water but also yields additional benefits. Abundant byproducts such as wheat straw, grass clippings, and leaf debris, which are commonly generated by producers, are currently expended as resources for disposal purposes (Ghosh *et al.,* 2006).

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 (Jacks et al., 1955). Its utility spans the regulation of soil moisture, soil temperature, mitigation of nutrient losses, salinity control, erosion prevention, 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 (Bandyopadhyay et al., 2009)

2 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 (Pirone 1941; Iqbal et al. 2020).

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 (Mendelsohn & Dinar, 2003)

3 Potential Water and Soil Management Benefits of Mulching

3.1 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 must be maintained in such a physical condition so as to allow adequate crop growth. Unless the soil 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

3.2 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 (Goulet, 1995; Chalker-Scott ,2007). 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 (Kudinov, 1972; Einert et al., 1975; Fraedrich & Ham, 1982; Long et al., 2001; Kader et al., 2019). 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 (Montague & Kjelgren 2004). Among inorganic solid-type mulches, gravel mulch has demonstrated superior temperature-regulating properties, surpassing materials such as concrete (Iles & Dosmann 1999; Montague & Kjelgren 2004).

Conversely, synthetic mulches have proven to be inefficient in temperature regulation, often elevating soil temperatures rather than maintaining them at desirable levels (Duncan et al., 1992; Litzow & Pellett, 1993; Walsh et al., 1996; Montague & Kjelgren, 2004; Chalker-Scott, 2007; Kader et al., 2019). Similarly, hydrophobic natural mulches like pine bark have been observed to induce greater water loss through nearby leaves and elevate soil surface temperatures (Zajicek & Heilman, 1994). Thus, the careful selection of an appropriate mulch in consideration of local climatic conditions and its inherent characteristics is of paramount importance.

Moreover, the thickness of the mulch layer should be meticulously determined, as heavy mulches have demonstrated more pronounced positive effects on temperature regulation compared to thin applications on the soil surface (Van Nierop & White, 1958; Horowitz & Thomas, 1994).

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 (Schales and Sheldrake, 1963). Research by Anikwe et al. (2007) 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 (Aniekwe et al., 2004)

3.3 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 (Kader et al., 2019). 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 (Kacinski 1951; Arthur & Wang, 1999; Lakatos et al., 2000). Commonly utilized mulch materials for retaining soil moisture include livestock waste, crop residues, and various types of stone gravels (Buban et al. 1996; Siipilehto, 2001).

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 (Li et al., 2001). Enhancing water use efficiency through optimized soil water utilization is a key strategy for increasing grain yields in semiarid regions (Zhao et al., 1995). 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 (Li et al., 1997).

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 grain yields (Kwabiah, 2004)

3.4 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 (Singh et al., 1991; Pickering & Shepherd, 2000; Ansari et al., 2001; Downer & Hodel, 2001). Nonetheless, it is noteworthy that Chalker-Scott (2007) 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 (Tisdale et al., 1990).

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

3.5 Improved plant establishment and crop growth parameters

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 performance. 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. (1999) 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.

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 (Li et al., 2004)

3.6 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 (Sharma & Bhardwaj, 2017).

Downer & Hodel (2001) 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.

3.7 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 (Chalker-Scott, 2007).

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 (1986), 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 (1963), Samarappuli & Yogaratnam (1984), Oliveira & Merwin (2001), and Tanavud et al. (2001).

Empirical evidence from Borst & Woodburn (1942) 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 (Megahan 1974).

3.8 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 (Lamont, 1993). The impact of mulches on the microclimate and energy balance of plants is contingent upon their ability to transmit, absorb, and reflect solar radiation (Lamont, 2005; Tarara,2000).

Incorporating ultraviolet reflectance can disrupt the host-seeking behaviour of thrips, resulting in a reduction in thrips populations in the vicinity of host plants (Brown and Brown, 1992; Kirk, 1997; Kring and Schuster, 1992; Scott et al., 1989). 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 (Brown and Brown, 1992; Kring and Schuster, 1992; Scott et al., 1989).

3.9 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. Plastic mulches cannot bind ions as organic mulches can and are not effective in this regard.

4 Biodegradable Mulches

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 (Sharma & Bhardwaj, 2017).

Downer & Hodel (2001) 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.

5 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 (Fontana et al., 2006). 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 (2013) 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. (2014) 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.

6 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 (Ramakrishna, et.al, 2005). 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 (Momirovic, et.al, 2010). 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 (Briassoulis, 2006).

7 Conclusion

In today's era of globalization and increased awareness of health, there is a growing global demand for horticultural crops. The utilization of plastic mulch has played a significant role in enhancing soil properties such as temperature, moisture levels, bulk density, aggregate stability, and nutrient availability. Moreover, plastic mulch 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.

References

[1] Anikwe M-A-N., Mbah C.N., Ezeaku P.I. and Onyia V.N. (2007). Tillage and plastic mulch effects on soil properties and growth and yield of cocoyam (Colocasia esculenta) on an ultisol in southeastern Nigeria. Soil and Tillage Research, 93, 264–272.

[2] Anikwe, N. L., Okereke, O. U. and Anikwe, M. A. N. (2004). Modulating effect of black plastic mulch on the environment, growth and yield of cassava in a derived savannah belt of Nigeria. Tropicultura., 22, 185-190.
[3] Ansari, R., Marcar, N. E., Khanzada, A. N., Shirazi, M. U. & Crawford, D. F. (2001). Mulch application improves survival but not growth of Acacia ampliceps Maslin, Acacia niloticaL. and Conocarpuslancifolius L. on a saline site in southern Pakistan. Int. J. Rev 3, 158–163.
[4] Arthur, M. A. & Wang, Y. (1999). Soil nutrients and microbial biomass following weed- control treatments in a Christmas tree plantation. J. Ame. Soc. Soil. Sci. 63, 629–637.
[5] Bandyopadhyay, K. K., Hati, K. M., and Singh, R. 2009. Management options for improving soil physical environment for sustainable agricultural production: a brief review. J. Agric. Phys., 9, 1-8.
[6] Borst, H. L. & Woodburn, R. (1942). The effect of mulching and methods of cultivation on runoff and erosion from Muskingham silt loam. J. Agric. Engin. 23, 19–22.
[7] Briassoulis D. 2006. Mechanical behaviour of biodegradable agricultural films under real field conditions. Polymer Degradation and Stability, 91: 1256–1272.
[8] Brown, S.L. and Brown, J.E. (1992). Effect of plastic mulch color and insecticide on thrips population and damage to tomato. Hort Technology 2:208–210.
[9] Buban, T., Helmeczi, B., Papp, J., Dorgo, E., Jakab, L., Kajati, I., Merwin, I., Polesny, F. & Muller, W. (1996). IFP-compatible ground-cover management systems in a new-planted apple orchard. 19, 263–267.
[10]Chalker-Scott, L. (2007). Impact of mulches on landscape plants and the environment - a review. J Environ Hortic 25, 239–249. Available from: http://www.gufc.org/wp-content/uploads/2010/12/Mulchreviewarticle(2).pdf.
[11]Costa R., Saraiva A., Carvalho L. and Duarte E. (2014). The use of biodegradable mulch films on strawberry crop in Portugal. Scientia Horticulturae, 173: 65–70.
[12]Donnelly, J. R. & Shane, J. B. (1986). Forest ecosystem responses to artificially induced soil compaction. I. Soil physical properties and tree diameter growth. Canad. J. Res. 16, 750–754.
[13]Downer, J. & Hodel, D. (2001). The effects of mulching on establishment of Syagrus romanzoffiana (Cham.) Becc., Washingtonia robusta H. Wendl. and Archontophoenix cunninghamiana (H. Wendl.) H. Wendl. and Drude in the landscape. Sci. Hortic. 87, 85–92.
[14]Duncan, R. A., Stapleton, J. J. & McKenry, M. V. (1992). Establishment of orchards with black polyethylene film mulching: effect on nematode and fungal pathogens, water conservation, and tree growth. J. Nemato. 24, 681–687.
[15]Einert, A. E., Guidry, R. & Huneycutt, H. (1975). Permanent mulches for landscape plantings of dwarf crape myrtles. Amer. Nurseryman. 142, 62–65.
[16]Fontana E., Hoeberechts J. and Nicola S. (2006). Effect of mulching in medicinal and aromatic plants in organic farm guest houses. Acta Horticulturae, 723, 405–410.
[17]Fraedrich, S. W. & Ham, D. L. (1982). Wood chip mulching around maples: effect on tree growth and soil characteristics. J. Arboric. 8, 85–89.
[18]Ghosh, P. K., Dayal, D., Bandyopadhyay, K. K., and Mohanty, M. (2006). Evaluation of straw and polythene mulch for enhancing productivity of irrigated summer groundnut. Field Crops Research, 99(2), 76-86.
[19]Goulet, F. (1995). Frost heaving of forest tree seedlings: a review. New. Forests. 9, 67–94.
[20]Horowitz, M. & Thomas, J. M. (1994). Couverture du sol pour la gestion des mauvaisesherbes (Soil cover for weed management). In: Maitrise des Adventices par Voie non Chimique. Communications de la Quatrieme Conference Internationale IFOAM, pp. 149–154.
[21]Iles, J. K. & Dosmann, M. S. (1999). Effect of organic and mineral mulches on soil properties and growth of 'Fairview flame R' red maple trees. J. Arboric. 25, 163–167.

[22]Iqbal, R., Raza, M. A. S. & Valipour, M. et al. (2020). Potential agricultural and environmental benefits of mulches – a review. Bull Natl Res Cent 44, 75. https://doi.org/10.1186/s42269-020-00290-3.
[23]Kacinski, N. A. (1951). Sowing oak in micro depressions as a means of combating drought on light chestnut soils. Pocvoved. 10, 585–603.
[24]Kader, M. A., Singha, A. & Begum, M. A. et al. (2019). Mulching as water-saving technique in dryland agriculture: review article. Bull Natl Res Cent 43, 147. https://doi.org/10.1186/s42269-019-0186-7.
[25]Kirk, W.D.J. (1997). Distribution, abundance, and population dynamics, p. 217–257. In: Thrips as crop [Lewis, T. (ed.)]. P. CAB International, Wallingford, UK.
[26]Kring, J.B. and Schuster, D.J. (1992). Management of insects on pepper and tomato with UV-reflective mulches. Fla. Entomol. 85:9–14.
[27]Kudinov, V. I. (1972). Sawdust instead of manure. Sadovodstvo 12, 38.
[28]Lakatos, T., Buban, T., Muller, W., Polesny, F., Verheyden, C. & Webster, A. D. (2000). Effectiveness of different groundcover materials to preserve soil water content in a young apple orchard. Acta.Hortic. 525, 425–426.
[29]Lamont, W.J. (2005). Plastics: Modifying the microclimate for the production of vegetable crops. Hort Technology 15:477–481.
[30]Lamont, W.J. (1993). Plastic mulches for the production of vegetable crops. Hort Technology 3:35–39.
[31]Li F. M., Wang, J., Xu, J.Z., and Xu, H. L. (2004). Productivity and soil reponse to plastic film mulching duration for spring wheat on entisols in the semiarid loess plateau of China. Soil and Tillage Research. 78: 9-20
[32]Li FM, Yan X, Wang J, Li , SQ and Wang T C. (2001a). The mechanism of yield decrease of spring wheat resulted from plastic film mulching. Agric Sci China 34:33 -333.
[33]Li FM, Guo A H and Wei H. (1999). Effects of plastic film mulch on yield of spring wheat. Field Crops Res 63:79-86
[34]Li F.M., Guo A.H. and Luo M. (1997). Effect of water supply from deep soil on dry matter production of winter wheat. Chin. J. Appl. Ecol. 8: 575–579.
[35]Litzow, M. & Pellett, H. (1993). Influence of mulch materials on growth of green ash. J. Arboric. 9, 7–11.
[36]Long, C. E., Thorne, B. L., Breisch, N. L. & Douglass, L. W. (2001). Effect of organic and inorganic landscape mulches on subterranean termite (Isoptera: Rhinotermitidae) foraging activity. J. Environ. Ento. 30, 832–836.
[37]Megahan, W. F. (1974). Deep-rooted Plants for Erosion Control on Granitic Road Fills in the Idaho Batholith, Vol. 161. US Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station
[38]Mendelsohn, R. & Dinar, A. (2003). Climate, water and agriculture. Land Economics, 79 (3), 328–341. doi:10.2307/3147020.
[39]Momiroviæ, N., Oljaea, V.M., Dolijanovic, Z., Postic, D. (2010). Energetska efikasnost proizvodnje paprike u zastiæenom prostoru u funkciji primene razlieitih tipova polietilenskih folija (PE), Poljoprivredna tehnika, 35(3), 1- 13.
[40]Montague, T. & Kjelgren, R. (2004). Energy balance of six common landscape surfaces and the influence of surface properties on gas exchange of four containerized tree species. Sci. Hortic. 100, 229–249.
[41]Oliveira, M. T. & Merwin, I. A. (2001). Soil physical conditions in a New York orchard after eight years under different groundcover management systems. J. Plant. Soil. 234, 233–237.
[42]Pickering, J. S. & Shepherd, A. (2000). Evaluation of organic landscape mulches: composition and nutrient release characteristics. Arboric. J. 23, 175–187.

[43]Pirone, P. P. (1941). Freak weather damages trees and shrubs. New. Jersey. Agric. 23, 3.
[44]Polara P. and Viradiya R. (2013). Effect of mulching material on growth, yield and quality of watermelon (Citrullus lanatus Thunb) Cv. Kiran. Universal Journal of Agricultural Research, 1(2), 30-37.
[45]Ramakrishna A.,Tam H.,Wani S. and Long T. (2005). Effect of mulch on soil temperature, moisture, weed infestation and yield of ground nut in northern Vietnam. Field Crops Research, 95(2-3), 115-125.
[46]Samarappuli, L. & Yogaratnam, N. (1984). Some aspects of moisture and soil conservation in rubber plantations. In: Proceedings of the International Rubber Conference. 75 Years of Rubber Research in Sri Lanka, September 1984, Colombo, Vol. 1, Part 2. Rubber Research Institute of Sri Lanka, Agalawatta, Sri Lanka, pp. 529–543.
[47]Sartz, R. S. (1963). Water Yield and Soil Loss From Soil-Block Lysimeters Planted to Small Trees and Other Crops. USFS Research Paper LS-6, St. Paul, MN, p. 23.
[48]Scott, S.J., McLeod, P.J., Montgomery, F.W. and Handler, C.A. (1989). Influence of reflective mulch on incidence of thrips (Thysanoptera: Thripidae:Phlaeothripidae) in staked tomatoes. J. Entomol. Sci. 24,422–427.
[49]Sharma, R. & Bhardwaj, S. (2017). Effect of mulching on soil and water conservation -A review. Agri Revi. 38 (4), 311–315. doi:10.5958/j.0976- 0741.34.3.003.
[50]Siipilehto, J. (2001). Effect of weed control with fiber mulches and herbicides on the initial development of spruce, birch and aspen seedlings on abandoned farmland. Silva.Fenn. 35, 403–414.
[51]Singh, S. B., Pramod, K., Prasad, K. G. & Kumar, P. (1991). Response of eucalyptus to organic manure mulch and fertilizer sources of nitrogen and phosphorus. Van.Vig. 29, 200–207.
[52]Stavisky, J., Funderburk, J.E., Brodbeck, B.V., Olson, S.M. and Andersen, P.C. (2002). Population dynamics of Frankliniella spp. and tomato spotted wilt incidence as influenced by cultural management in tomato. J. Econ. Entomol. 95, 1216–1221.
[53]Tanavud, C., Kheowvongsri, P., Yongchalermchai, C., Leowarin, W., Densrisereekul, O., Bennui, A., Muraseand, J. & Kimura, M. (2001). Effects of land use patterns on soil and water quality in Khlong U-Taphao Basin. Thai. J. Agric. Sci. 34, 15–31.
[54]Tarara, J.M. (2000). Microclimate modifications of plastic mulch. HortScience 35,169–180.
[55]Van Nierop, E. T. & White, D. P. (1958). Evaluation of several organic mulching materials on a sandy loam forest nursery soil. J. Fore. 56, 23–27.
[56]Walsh, B. D., Salmins, S., Buszard, D. J. & MacKenzie, A. F. (1996). Impact of soil management systems on organic dwarf apple orchards and soil aggregate stability, bulk density, temperature and water content. Canad. J. Soil. Sci. 76, 203–209.
[57]Zajicek, J. M. & Heilman, J. L. (1994). Transpiration by crape myrtle cultivars surrounded by mulch, soil, and turfgrass surfaces. J. Hortic. Sci. 26, 1207–1210.
[58]Zhao, S L, Li, F M and Wang, J. (1995). Discussion on development of water-harvested agriculture in semi-arid region Northwest China. Acta Botan Boreali-Occidental Sin, 15, 9–12.