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SOIL SCIENCE

Effect of mulch on soil thermal regimes - A review

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Abstract

Any material spread over the soil to assist soil and water conservation, and increase the productivity of soil is called mulch. The application of different types of mulch to soil is one of the corner stones of agriculture. Mulch may be organic or inorganic/synthetic in nature. Mulches are well-known for modifying the heat/energy and water balance at the surface of soils and creating more favorable conditions for plant growth. Soil thermal regimes can be modified by using different kinds of mulches. Soil temperature is agriculturally more significant than aerial temperature. Extensive research in the past indicates that mulches modify soil hydrothermal regimes in crop root zone, conserve soil moisture, keep down weeds and promote soil productivity. Mulch influences the hydrothermal regimes by changing radiation balance, rate of heat and water vapor transfer and heat capacity of soil. However, the magnitude of the desired effects depends on the quality, quantity, durability of mulch material, soil type and climatic conditions. In the era of climate change, mulching materials should be extensively used especially under rainfed conditions for soil and moisture/water conservation, temperature moderation, soil health maintenance and finally towards the increased agricultural productivity. The economics and environmental concerns should also be taken into account while selecting the mulch material.

Highlights

- Soil temperature is agriculturally more significant than aerial temperature
- Different types of mulch can be used to modify soil thermal regimes which lead to better crop production.
- Under rainfed condition mulching is required for soil and moisture/water conservation, temperature moderation, soil health maintenance
- Economics of mulching should also be taken into account while selecting the appropriate mulching materials.

Keywords: Mulch, soil temperature, solarization, hydrothermal regimes, crop residue mulch, plastic mulch

Mulch means a layer of dissimilar material separating the soil surface from the atmosphere, and mulching is the artificial application of mulch, practiced to obtain beneficial changes in the soil environment (Acharya *et al*. 2005). Any material spread over the soil to assist soil and water conservation, and increase the productivity of soil is mulch. Mulching is a crop production and soil protection) technique that involves placement of organic or inorganic materials on the soil surface so as to provide a more favorable environment for plant growth and development (Kamal and Singh 2011). The application of different types of mulch to soil is one of the corner stones of agriculture. Mulch may be organic (crop residues, stubble mulch, etc.) or inorganic/synthetic (plastic sheet, gravels, etc.) in nature. It may be grown *in situ* like previous crop residue mulch left on the surface, produced by a cover crop or it may be living mulch like perennial legumes mulch. It may also be grown or produced *ex situ* and brought in for field application, e.g., straw, saw dust, plastic products etc.

Mulches are well-known for modifying the heat/energy and water balance at the surface of soils and creating more favorable conditions for plant growth. Mulches conserve soil moisture by retarding evaporation (Hillel 1982), but effects on soil temperature vary depending on the composition and optical properties of the mulch (Ham *et al.* 1993). In general, polyethylene mulches increase maximum and minimum soil temperatures relative to un-mulched soil (Ham *et al.* 1993), whereas, organic mulches decrease maximum but increase minimum soil temperature (Teasdale and Mohler 1993). Mulches are known to increase soil temperature since the solar energy passes through the mulch and heats the air and soil beneath the mulch directly and then the heat is trapped by the ''greenhouse effect'' (Hu *et al.* 1995). The growth of crop plants from germination to maturity depends on the interdependency of genetic and environmental factors, which determine the timing and rate of development of crop. Among the various environmental factors, temperature is probably the most important (Likatas *et al.* 1986). Soil temperature is a measure of the intensity of heat in soil. Soil temperature is affected by heat exchange with air or the atmosphere heat flow in soil and consumption or production of heat in soil (Ramakrishna *et al.* 2006). Thermal properties of soils play an important role in influencing microclimate, which influences seed germination, seedling emergence, root growth and subsequent stand establishment (Fan *et al.* 2012). Crops encounter sub or supra-optimal temperature at some stages of crop growth periods. The crops grown during summer experience higher temperature than those are grown during winter. Modifications of hydrothermal regimes by application of mulches or by adopting suitable management practice can result in enhancing crop production.

Soil temperature is agriculturally more significant than aerial temperature with respect to crop growth (Chaudhary and Prihar 1974; Gan *et al.* 2013). Soil temperature is one of the most important factors that affect the soil heat storage, soil heat flux, soil water flux, seed emergence, nutrient transformation, transport, uptake and plant growth. The functional activity of plant roots can be affected both at low and high soil temperatures. Most of the plant responses alter with changing temperature, with lower and upper threshold values and a prominent optimum (Pollock 1990). Favourable soil temperature for the growth of nitrogen fixing bacteria generally ranges from 20 to 25^{o}C. The optimum soil temperature varies from 15-27^{o}C for wheat, 25-30^{o}C for sorghum and rice, and 25-35^{o}C for corn crop (Oswal 1993). The objective of this paper is to review the effect of organic and inorganic mulches on soil thermal regimes and hence their possible impacts to crop growth and yield.

Classification of Mulch

Different mulches offer different definite characteristics. Based on the constituents of mulch, the different mulch types are:

1. Inorganic or Synthetic mulch

Inorganic mulches, such as stone or plastics, or geotextiles tend to stay in place. They have numerous disadvantages when used in the garden. Stone mulches can migrate down into the soil in time, making future digging difficult. Light-colored stones can reflect heat onto plants, scorching sensitive plants. Stones also tend to work free of beds and can be thrown by lawn mowers, potentially causing injury. Perhaps the greatest disadvantage is that these mulches do not contribute organic matter to your soil.

Table 1. Mean soil temperature in the morning and at noon during 1999/2000 and 2000/2001 seasons in Sudan (Abu-Bakr *et al.* 2003)

Treatments	Time	Soil temperature		
		1999/2000	2000/2001	Average
Black mulch	*Morning*	20.8	25.4	23.1
	Noon	24.9	29.8	27.4
Clear mulch	*Morning*	22.6	27.0	24.8
	Noon	27.6	32.7	30.2
Green mulch	*Morning*	22.1	26.7	24.4
	Noon	27.0	32.5	29.8
Weeded control	*Morning*	18.2	22.0	20.1
	Noon	23.2	27.6	25.4
Weeded control	*Morning*	17.5	20.8	19.2
	Noon	22.0	26.2	24.1
LSD $_{(5\%)}$	*Morning*	0.6	1.0	0.7
	Noon	0.9	0.8	1.2

(a) Plastic films

These are widely used as a mulching material. Out of all the mulch types, Plastic films help in water retention in soil by reducing evaporation, inducing infiltration and by reducing transpiration from weeds. They can be expensive, and are difficult to manage over large scale field conditions, when cultivating low value crops. Traditionally, plastic mulches are black or white. However, different coloured mulches have also been tried by researchers showing positive effect on potato yield throughdecreased rise in soil temperature (Ibarra-Jiménez *et al.* 2011).

(b) Crushed stone, gravel, soil or dust mulch

This technique involves applying a layer of crushed stone, gravel or soil on surface soil layer, so that it acts as mulch. This loose layer of soil reduces evaporation, thus helping in retention of water, as well as preventing the soil from cracking up, by acting as fillers and breaking the capillary continuity. These mulches are available in a wide variety of textures, colors, and materials and are used in rock gardens, driveways, and walkways.

(c) Petroleum products

These are more economical than plastic films, and are easier to maintain and apply. Examples are petroleum, asphalt sprays and resins.

(d) Geotextiles

These are fabric mulches of polypropylene or polyester. They work much as plastic does, but allow water and fertilizer to enter the soil. For the best weed suppression, choose closely woven geotextiles should be used. Generally the fabric is placed on weed-free ground and covered with mulch, such as wood chips, to improve its appearance, keep it in place, and reduce damage to the fabric by the sun's rays.

2. Organic or biological mulch

Mulches made from plant material are organic mulches. With time, organic mulches decompose and become a part of the soil. This decomposition adds organic matt er to soil and helps in improving water and nutrients retention capacity of soil and promotes the growth of healthier plants. However, organic mulches will have to be replenished from time to time.

(a) Crop residues or stubble mulch

Residue from crops and other waste products are oft en used as mulch. They are available in and around the area of application in abundance. They reduce evaporation, thereby increasing water content in the soil. A few good examples of this are dry grass, wheat, and gram stalks.

(b) Vertical mulch

In dry areas, when there is a rain, it generally is of an extreme nature resulting in severe soil erosion and runoff. To prevent this, a new technique is being used in which trenches are dug all across in between the crop lines so as to absorb the excess runoff water. The trenches are filled up with straw stubbles and stalks to prevent silting. The trenches absorb the excess water, and redistribute around the area, thereby reducing soil erosion due to runoff. Vertical mulch can provide 3 to 4 years of consistent service.

Impacts of Mulching Materials

1. Mulches and soil temperature

Soil thermal regimes can be modified by using different kinds of mulches. Mulches of various thermal and optical properties result in varied degrees of soil warming by incoming solar radiation. Thermal regime of a soil depends on radiant energy incident at the soil surface, heat flux into the soil as determined by soil thermal characteristics and heat exchange between the soil and air. Mulches, by modifying the soil thermal regime and above ground temperature, may affect plant growth, development and crop production (Likatas *et al*. 1986). Mulches can reduce evaporation in many ways by intercepting incident radiation, acting as physical barriers for the loss of vapour to the atmosphere and avoiding direct contact of turbulent air through lowering of vapour pressure gradient (Acharya *et al.* 2005). In addition, combination of optimumsoil temperature and soil moisture favour microbial activity (Kaschuk *et al.* 2010), and supplied more substrates for microbial biomass by increasing plant root growth (Yao *et al.* 2011) under mulching. Mulches modify soil hydrothermal regimes in crop root zone, conserve soil moisture, keep down weeds and promote soil productivity. Application of mulch treatments (FYM and cluster bean mulches) was found effective by buffering the soil hydrothermal regimes under brinjal cultivation in Bikaner, Rajasthan (Singh *et al.* 2011)

Plastic Mulch and Soil Temperature

Plastic mulches are highly effective in moisture conservation and in alleviating sub optimal temperature conditions (Yi *et al.* 2011). Surface residue cover can affect soil temperature by insulating the soil surface and slowing down soil drying in the spring (Fortin 1993; Kasper *et al.* 1990) besides reducing soil erosion and surface runoff (Cruse *et al.* 2001). Wolfe *et al.* (1989) observed that clear polyethylene mulch increased soil temperature more than black mulch, but black polyethylene mulch increased air temperature more than clear mulch beneath tomato and cucumber crops. Liakatas *et al.* (1986) reported that black and reflective mulches may reduce the diurnal amplitude of soil temperature and always reduce the radiant heat gain by the soil;whereastransparent mulches resulted in a relatively large net radiation at the soil surface. Contreras *et al.* (1992) concluded that the thermic levels of soil under smoke-grey polyethylene mulches are slightly higher than transparent polyethylene mulches. Opaque black polyethylene mulches caused poor heating of soil during hot hours, but preserved heat at night. Byun *et al.* (1991) observed that soil temperature at 10 cm depth was always higher with polyethylene mulches than straw mulches or no mulch.

Kamara (1986) observed that maximum soil temperature at 5 cm depth under bare fallow, cropped and un-mulched plots were 44 and 40^{o}C, respectively, while the cropped and mulched tillage plots had maximum soil (at 5 cm depth) temperature of only 35^{o}C. Yi (1988) observed that the temperature gradients within the soil increase, if the ground is covered with plastic film. This creates an acceleration of water movement from deep to shallow levels within the soil, as soil moisture is constantly transported from hot to cold regions. If the surface was loose, air filled porosity at low water content would induce temperature gradients with greater temperature gradients near the surface, the downward movement of water would be highest in this areas.

Kamal and Singh (2011) showed that the highest soil temperature occurred under black polyethylene which was 2.2 – 3.4°C more than the bare soil (Figure1). In general, this effect was more evident during the early crop season when tomato plants shaded less soil surface area. Black plastic mulches are more effective in increasing soil temperature due to absorption of greater net radiation under the mulch compared to bare soil.

Plastic mulches absorb large amounts of the incoming radiation and transmit a considerable part of it to the soil underneath (Tarara 2000). The surface energy balance of plastic mulchand its influence on the crop environment are determined by the optical properties of the plastic (Ham *et al.* 1993). Kiss (1972) found that transparent polyethylene transmitted about 75% of the thermal radiation compared to 20 to 40%transmission obtained with black polythene, depending on pigmentcontent. Additionally greenhouse gas like N_2O was also found to reduce under ridge furrow mulching system as mulches acted as a physical barrier to the gas from soil to the atmosphere (Gan *et al.* 2012). The thermal transmission efficiency might have resulted in better heat conservation under the black mulch during thenight, explaining the higher temperature differences in the morning than atmid-day under the black polythene mulch.Black polythene mulch was also found superior for vegetables like lettuce (Sultana *et al.* 2011), and okra and squash (Mahadeen 2014) by increasing soil temperature and conserving soil moisture.

Crop Residue Mulch and Soil Temperature

Surface application of wheat straw at 7.5 tonnes/ha reduced the maximum soil temperature from 37.1 to 28.6ºC in Brazil(Bgragagnolo and Mielniczuk 1990). The soil temperature was lower for all layers under wheat residue mulch (Kalra *et al.* 1984). Lowering of soil temperature and narrowing down diurnal temperature fluctuations in the top few inches of the soil by straw mulchinghave been reported by Moody *et al.* (1963). Further, Tomar and Verma (1985) reported that the mulching of paddy straw at 5 or 10 tonnes/ha reduced fluctuations in soil temperature and delayed all growth stages of early and late sown wheat. Aggarwal *et al.* (1998) reported that in rainfed maize, application of weed mulch at 1 q/ha at tasseling,coinciding with time of recession of monsoon, conserved 1.5-2 cm more water, reduced temperature by 4-5°C at 5 cm and 2-4°C at the 15 cm soil depth, increased volumetric heat capacity by 0.01-0.02 calories/cm/°C and thermal conductivity by 1-2 x 10^{-3} calories/cm/sec/°C and, thus, checked diurnal temperature and evaporation both in ridge and flat-bed treatments. It has been found in literature that the mean temperature of 0-2.5 cm layer of crusted soil was slightly higher than un-crusted soil during the emergence of cotton (*Gossypiumhirsutum* L.) and pearl millet (*PennisetumglaucumL.).* The application of FYM at 25q/ha on seed lines has no effect on temperature of (0-2.5) cm layer but the application of wheat *bhusa* @15q/ha on seed lines reduced the temperature of this layer by 1° to 3°Cduring seedling emergence.

Sarkar and Singh (2007) studied the interactive effect of tillage depth and mulch on soil temperature, productivity and water use pattern of rainfed barley (*Hordiumvulgare* L.) and observed that soil temperature decreased with the decrease in ploughing depth at 07:00 but increased at 14:00, and soil dust and straw mulching increased soil temperature over the un-mulched condition at 07:00 but decreased it at 14:00, and the impact of tillage depths and mulching on soil temperature lasted for 75 days after sowing of barley. The application of straw mulch can lower maximum soil temperature due to the interception of incoming solar radiation, high reflectivity, and low heat conductivity, the management of which depends upon soil wetness, incidental radiation,rate of mulch application as well as period of the year.

Mulch and soil thermal properties

Mulches can also alter radiant heat transfer and modify landscape surface energy balances (van Donk and Tollner 2001). Montague and Kjelgren (2004) reported that daytime long wave radiation fluxes in the air above pine bark mulch were greater than those above several inorganic mulches or turfgrass. Typically, during nights and winters, organic residue mulch covering a soil reduces soil heat loss to a colder atmosphere. Because of this thermal insulation and because the mulch albedo (short wave reflectance) is higher than that of the soil, surface mulches reduce soil temperature amplitude, so that temperature extremes are less in mulch covered soil compared with those in a bare soil. Mulches affect the radiation balance and also affect heat and vapor transfer by conduction, convection, and evaporation. Reduction of springtime surface soil temperatures under surface mulch can have either positive or negative consequences, depending on the climate. In temperate climates, soil usually is cold and wet and solar radiation at the start of spring is low. Of en, higher soil temperatures are required to get crop growth and development started. Mulch can be a negative factor in this process by keeping the soil wet and cold for longer periods than would be the case for bare soil, thus shortening the length of the growing season (Horton *et al.* 1996).

Mulch and optical properties

The soil temperature under plastic mulch depends on the optical properties (reflectivity, absorptivity, or transmit ance) of a particular material. Black plastic mulch is an opaque black body absorber and radiator, absorbing most of thevisible and infrared wavelengths of incoming solar radiation and re-radiating the absorbed energy in the form of thermal radiation or long wavelength infrared radiation. Much of the solar energy absorbed by black plastic mulch is lost to the atmosphere through radiation and forced convection. The efficiency with which black mulch for increasing soil temperature can be improved by optimizing conditions for transferring heat from the mulch to the soil. Since, the thermal conductivity of the soil is high relative to that of air, a large proportion of the energy absorbed by black plastic can be transferred to the soil by conduction, if there is a good contact between the plastic mulch and the soil surface.

On the other hand, clear plastic mulch absorbs lit le solar radiation but transmits 85 to 95%, with the relative transmission depending on the thickness and degree of opacity of the polyethylene. The lower surface of clear plastic mulch is usually covered with condensed water droplets. This water is transparent to incoming short-wave radiation, but is opaque to outgoing long-wave infrared radiation. So much of the heat lost to the atmosphere from a bare soil by infrared radiation is retained by clear plastic mulch.

Effect of Modification of Soil Thermal Regimes on Crop Growth

Raising the soil temperature promotes more rapid crop development and earlier yields (Clarkson and Frazier 1957). Researchers have demonstrated earlier (7 to 14 days and up to 21 days) and increased yields (normally two to three times that of unmulched soils) depending on geographic location, soil type, plastic mulch used, and crop. The role of mulch in improving crop yield has been reported in different crops viz., okra (Brown *et al.* 1986); and tomato (Kamal and Singh 2011) (Figure 2).

Comparison of Plastic (Synthetic) and Crop Residue (Biological) Mulch

Organic and inorganic surface mulches have been shown to moderate temperatures within the root zone of landscape trees and shrubs. In a temperate climate, soil temperatures at 10 cm below organic mulches were approximately 2.5°C lower than in soil under inorganic mineral mulches (Iles and Dosmann 1999). The maximum soil temperature undergrass mulch, applied at the rate of 6 t ha^{-1}, decreased by 1 to 9°C. Paddy straw mulched treatment resulted in lower minimum and maximum soil temperatures compared to polyethylene mulch, probably because the black polyethylene absorbed more solar radiation compared to paddy straw mulch (Kalaghatagi *et al.* 1988). Gupta *et al.* (1994) found the higher surface temperature under black as well as transparent mulches compared to other treatments such as straw mulch and control. The soil temperature at 5, 15, 30 cm depths were found lowest under straw mulch for mustard (*Brassica juncea* L.) and moongbean (*Vignaradiata* L) crops. Moreover, the amplitude of diurnal fluctuations of soil temperature was highest under black polyethylenemulch compared to others.

Mulching by the crop straw reduces the soil temperature more effectivelyas compared to thesynthetic mulch like plastic film (Fan *et al.* 2012). Ross *et al.* (1985) reported that vegetative mulch reduced soil temperature by up to 20°C and mulch also prolonged the process of slow evaporation from the surface. The resulting higher soil water content also decreased soil surface temperature through its effects on soil thermal properties. Morate *et al.* (1991) observed that mean weekly temperature at 09:00 hrs varied lit le but there were remarkable variations among mulch treatments at 15:00 hrs. Mulching with wheat straw reduced soil temperature by 8°C, whereas in bare soil the temperature reached as high as 38°C. The temperature of irrigated plots was 28-30°C at 15:00 hrs due to the soybean canopy, whereas poor plant grown on non-irrigated plots resulted in soil temperature of 36°C.

Cook *et al.* (2006) reported that forthe organic mulches, temperature beneath wheat straw was lower than that under FYM compost and the control and for the inorganic/synthetic mulches. Black mat ing and black polyethylene mulch usually had higher temperature than bare soil. In the same study, it was found that soil temperature at 0.15 m taken around 16:00hrs was significantly reduced by application of wheat straw mulches. In the morning soil temperature was less by 2°C for wheat straw rates of 4, 6 and 8 t ha^{-1} compared to the no mulch treatment. In the af ernoon also, same trend was found. Insulation provided by mulch was overtaken by a standing crop as the canopy progressively increased shading of the soil surface (Dekker and Ritsema 1997).

Soil temperature at surfacewas 1-3°C higher on bed compared to flat method of sowing in sandy loam soils of New Delhi, India. Similarly,soil temperature (ST)under different manure types were of the order charcoal + compost > no manure >green manure. ST of surface under transparent polythene was 5-6 °C higher value over no polythene but these differences narrowed down with increase in depth (Figure 3 and 4) (Maity 2008; Maity and Aggarwal 2012). Similar type of result was also previously observed by Zhang *et al.* (2005) and Wilson and Jasa (2007).

Ramakrishna *et al.* (2006) showed that the polythene-mulched soil had significantly higher temperature (P at 0.05) at 5 and 10 cm soil depths during both seasons compared to chemical and unmulched treatments. On the other hand, straw-mulched soil recorded higher temperature at all growth stages compared to chemical and unmulched treatments, except at 06:00 hrs in spring, 2000 and at 30 and 90 days af er sowing (DAS) in autumn–winter (Figure 5 a-b, 6 a-b). Mean soil temperature at 5 cm depth ranged from a high of 37.7 °C (3 DAS) to 25.0°C (90 DAS) in polythene mulch to a low of 34.7°C (3 DAS) to 21.7°C (90 DAS) in un-mulched treatments. While at 10 cm depth, the mean soil temperature ranged from a high of 33.1 °C (3 DAS) to 21.6 °C (90 DAS) in polythene mulch to a low of 30.9 °C (3 DAS) to 18.7 °C (90 DAS) in chemical and un-mulched treatments. No significant differences in soil temperature were recorded among polythene and straw mulch treatments at both the soil depths. Generally, polythene mulch, followed by straw mulch, resulted in the highest soil temperatures. Further, the range of temperature difference was narrower at 10 cm depth than at 5 cm depth for any selected date. Choi and Chung (1997) observed that thermistors placed at soil surface recorded increase in soil temperatures by 2.8–9.4°C and 0.9–7.3°C at 5 cm depth due to mulching. Park *et al.* (1996) also observed an increase in average soil temperature by 2.4°C at 15 cm depth under transparent film and an increase of 0.8°C under black film. The results show that different mulching materials have varying effects on soil temperature. These are consistent with the results of Hanada (1991), who observed that polythene films (black, green or transparent) markedly increased soil temperature comparedto grass mulch in temperate, sub-tropical andtropical regions. Dionne *et al.* (1999) observed thatinsulating material covers such as wood mat and strawaffect the soil temperature, and the characteristics of protective soil covers also influence the soil temperature variation ranges. Further, the investigation showed that the polythene mulch offers bet er insulation than the other mulches and hence increase in soil temperature. The optical properties of the mulch and the degree of contact between it and the underlying soil modify the partitioning of the available net energy at the air–mulch and mulch–soil interfaces, with direct consequences on the heat transfer processes – radiation, convection and conduction – at these interfaces. Moreover, the mulch acts as a barrier to evaporation (Liakatas *et al.* 1986), enhancing the predominance of sensible heat exchange and influencing the dynamics of the soil temperature and humidity, and the amount of heat stored in or released from the upper layer of the soil (Berninger 1989).

Black mulches increased soil temperatures more than the clear mulches, whichsuggested that heat transfer between the soil and plastic was an importantmechanism. Thus, the degree of contact between mulch and soil, of en quantifiedas a thermal contact resistance, probably affected mulch performance. Abu-Bakr *et al.* (2003) in Sudan showed that Soil temperature was significantly higher under the plastic mulches than the control. It increased soil temperature by 5.6°C, 5.2°C and 3.9°C in the morning and 6.1°C, 5.7°C and 3.3°C at midday under the clear, green and black mulches, respectively, compared to the control (Table 1).

Mulch and Soil Solarization

Soil solarization is an application of soil mulching to increase soil temperatures to such levels that are lethal to microorganisms to cause diseases in crops of economic importance. It causes hydrothermal disinfestation and other physical and biological changes in soil which are beneficial to plant health and growth. During solarization, soil is covered with mulch that reduces heat losses without significantly interfering with the absorption of solar energy, resulting in increased soil temperatures. Plastic film laid over moist soil during periods of high air temperature, usually for 1–2 months, can greatly reduce or eradicate a number of pathogens and pests including fungi, bacteria, nematodes, arthropods and weeds. Following soil solarization, growth of microflora beneficial to plant growth or antagonistic to pathogens and pests may slow the re-infestation of soil by these organisms for more than one growing season. Increased plant growth and yield of annual and perennial field, row and nursery crops usually occur following soil solarization. In addition, the increased availability of mineral nutrients following solarization may reduce crop fertilization requirements. Soil solarization has been effective as a pre-plant and post-plant treatment, and has been compatible with chemical soil treatments and also biological soil amendments af er solarization. Mulches used for solarization are films of plastic polymers, usually polyethylene (PE), polyvinyl chloride (PVC), or ethylene-vinyl acetate (EVA). PE films are most widely used for this purpose. Among the desirable characteristics that make PE films popular are tensile strength, resistance to tearing when exposed to strong winds and low cost. Chellemi (2002) and Singh (1998) in their works on solarization concluded that temperatures recorded from solarized mulched soils were observed to be higher than those obtained from solarized non-mulched soils. At 60 days of plastic coverage (DPC), the solarized mulched plot recorded a higher temperature of 38.8°C and 37.7°C, respectively for the year 2004 and 2005 compared to that recorded from the non-mulched plots (Chellemi 2002) (Figure 7).

Alkassy and Alkaraghouli (1991) tested the performance of different color plastic mulches for soil solarization and reported that soil temperatures decreased for the colors in the following order: red, transparent, green, blue, yellow and black. Traditionally, soil solarization has been implemented using either transparent or black mulches. Chase *et al.* (1999) observed that soil temperatures under transparent film were higher than that under black film mulch, while Ham *et al.* (1993) reported the opposite results. Transparent plastics are usually considered to be more effective for soil heating, especially for soil solarization (Stapleton 2000), but black mulches may increase soil temperature more than the clear ones with respect to highersoil heat flux, ground net radiation and both air and root-zone temperature (Bonachela *et al.* 2012).

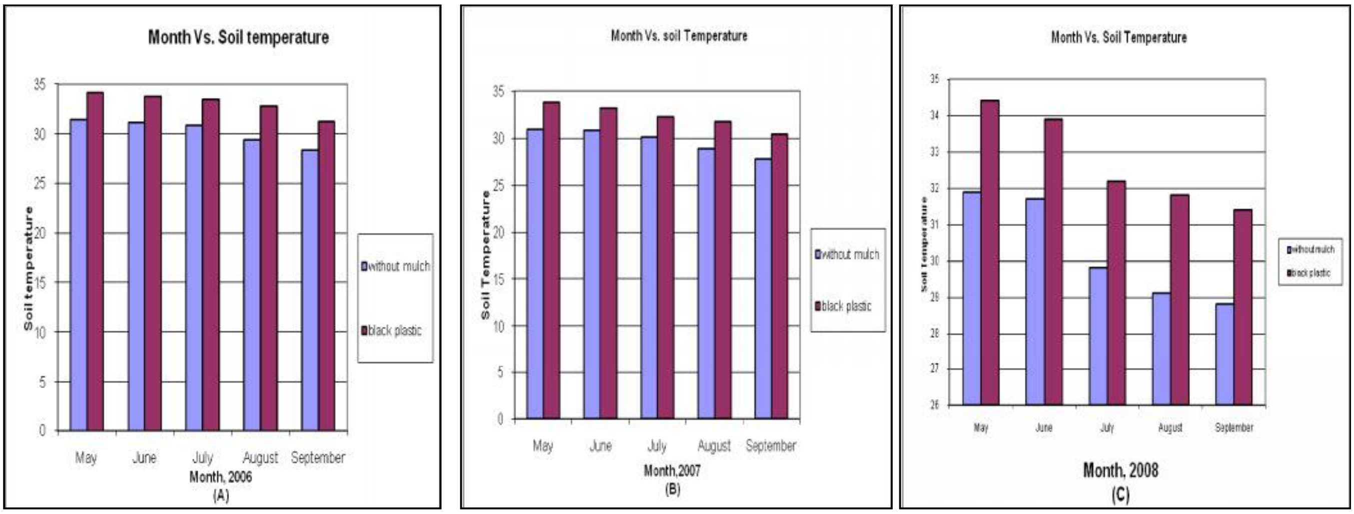


Fig. 1. Effect of black plastic mulch on soil temperature (Source: Kamal and Singh 2011)

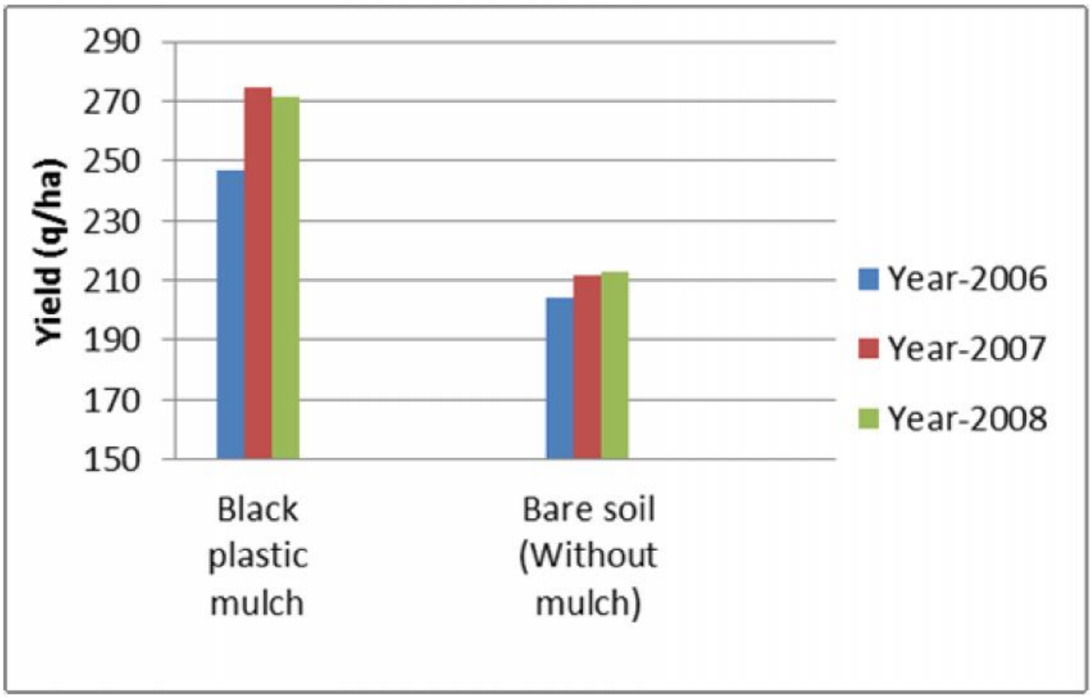


Fig. 2. Effect of black plastic mulch on tomato yield (Source: Kamal and Singh 2011)

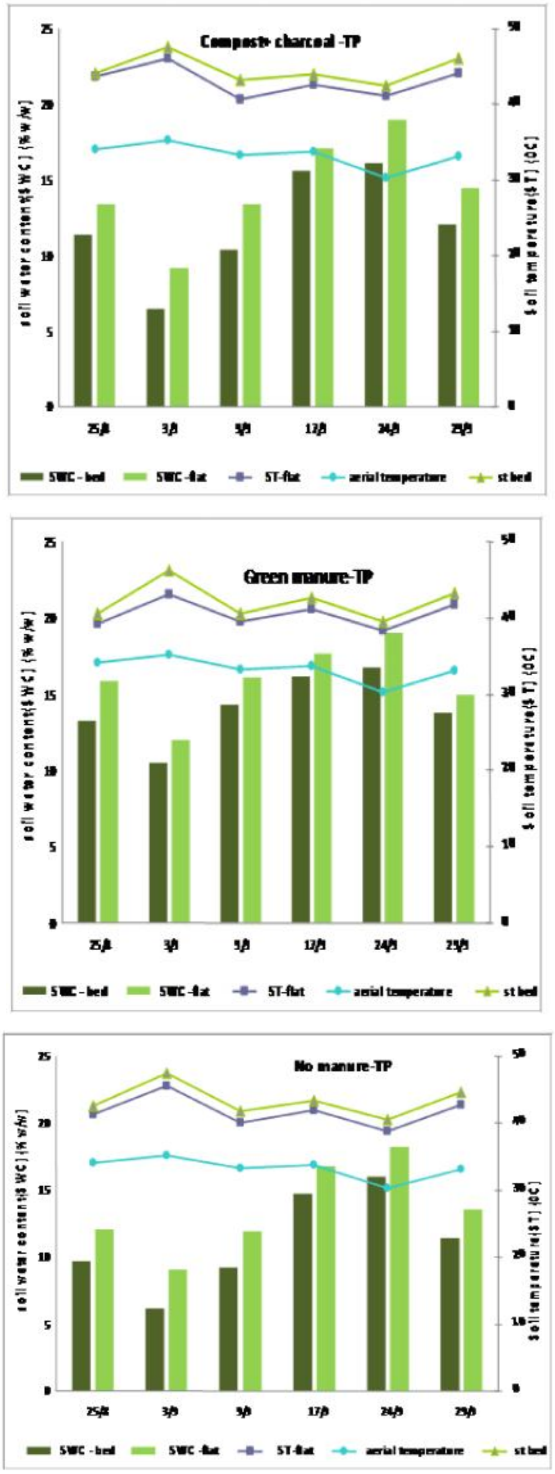


Fig. 3. Temporal variation of surface soil temperature in different manure treatments and land configuration under mulch condition (Source: Maity 2008)

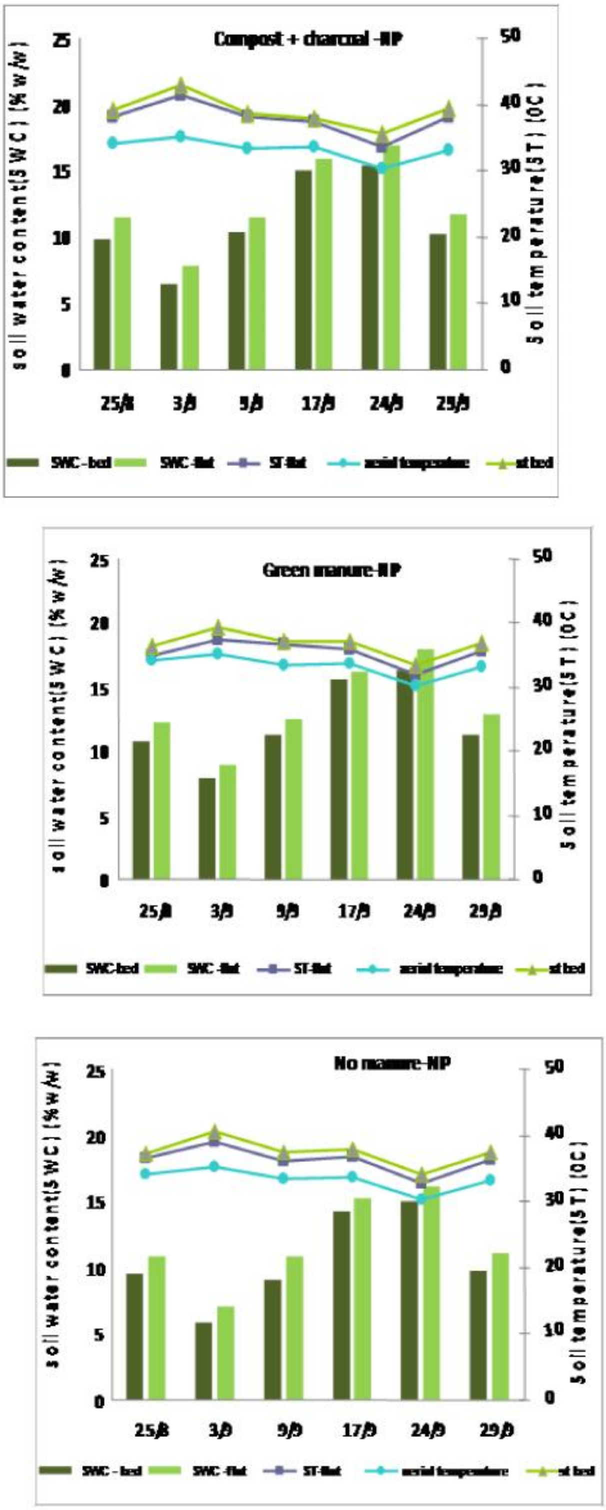
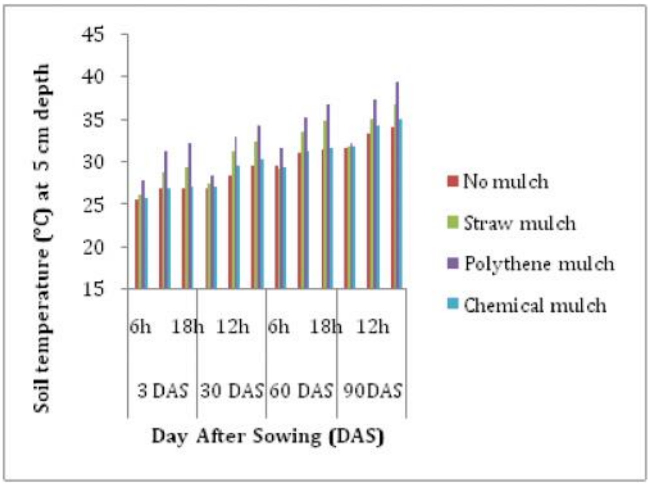
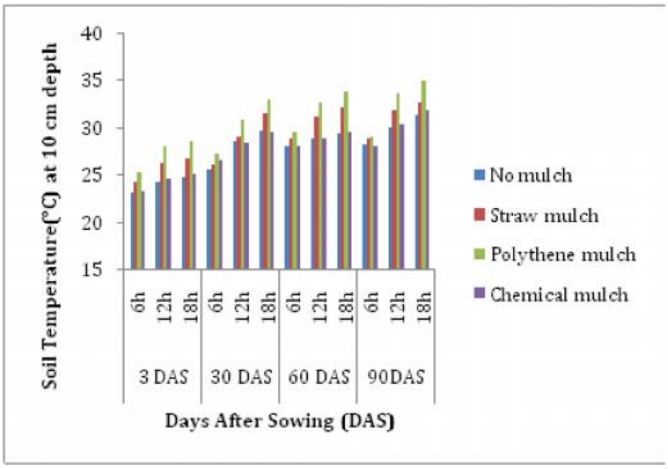


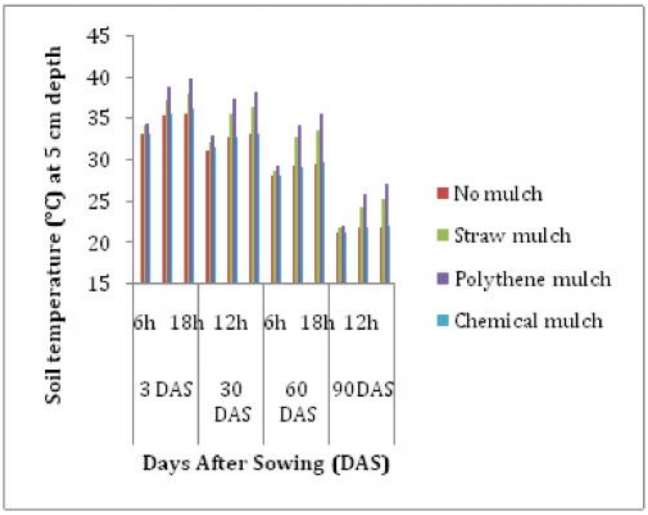
Fig. 4. Temporal variation of surface soil temperature in different manure treatments and land configuration under no mulch condition (Source: Maity 2008)



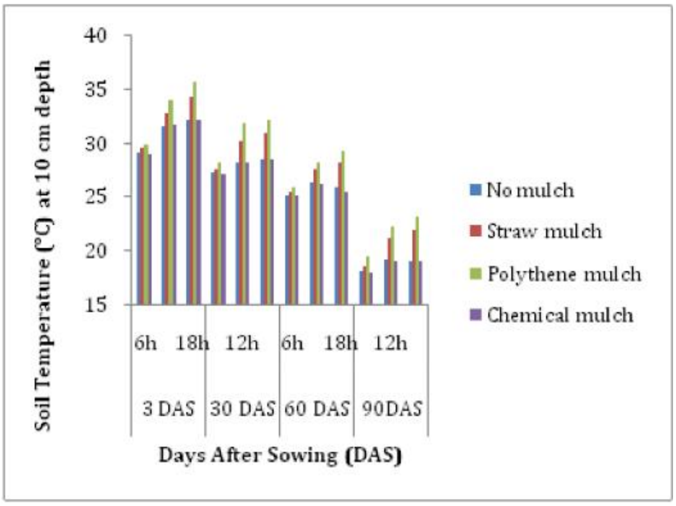
5(a)



5(b)



6(a)



6(b)

Fig. 6. Soil temperature in mulch treatments at (a) 5 cm and (b) 10 cm depth in Vietnam during Spring, 2007 (Source: Ramakrishna *et al.* 2006)

Conclusion

From the above review, it can be concluded that in the climate change era (with increased frequency of heavy rainfall and high terminal heat), mulching materials should be extensively used especially under rainfed conditions for soil and moisture/water conservation, temperature moderation, soil health maintenance and increased productivity. Different types of mulch can be used to modify soil thermal regimes which lead to bet er crop production. Selection of mulch material depends on many factors likes purpose of mulching, types of soil and climate etc. The success of mulching has resulted in commercial production of range of mulch materials that have a series of combination of optical properties. The complexity of energy exchange between the soil, mulch, and atmosphere makes it difficult to select the best mulch for a particular application. The development of new mulches can be challenging because traditional field

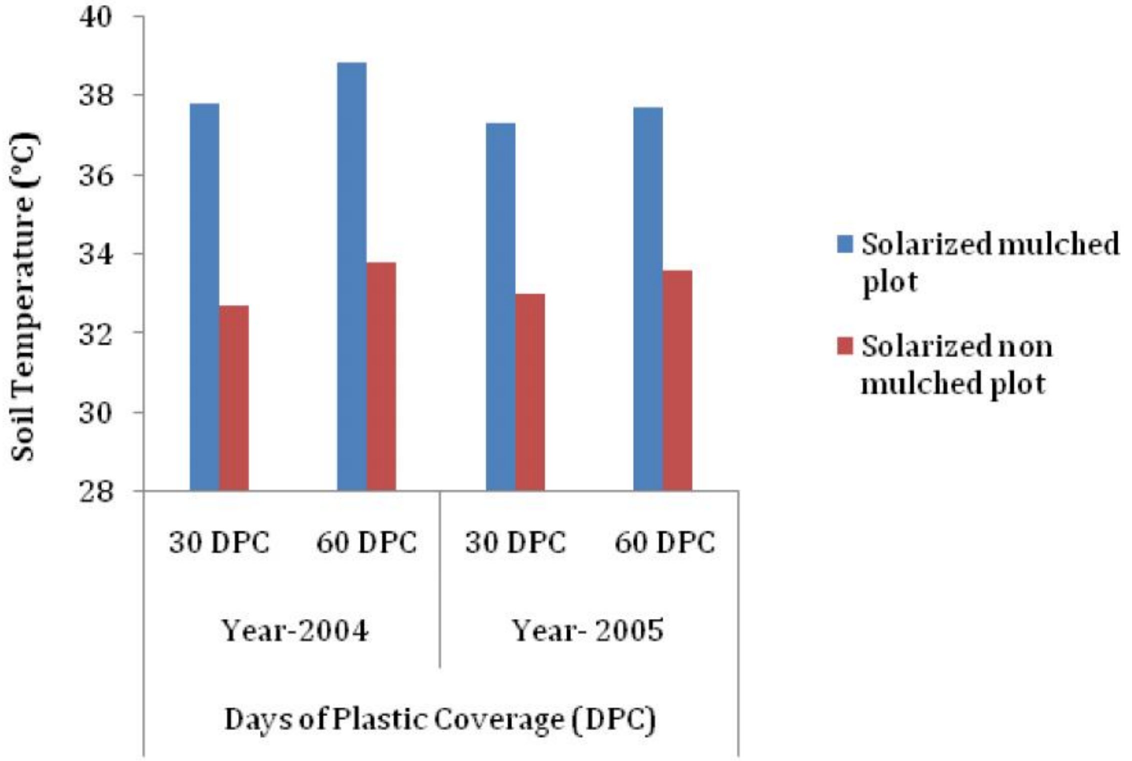


Fig. 7. Soil temperature levels from mulched and non-mulched plots at the specified days of plastic coverage (DPC) at AnseBoileau, Seychelles for the year 2004 and 2005 (Source: Chellemi 2002)

trials are oft en used to determine if experimental mulch is effective. Use of transparent polythene as mulch in modifying soil thermal environment is well known but the effect of different thicknesses of polythene on extent of increase in the soil temperature is yet to be investigated. Now-a-days, there is a lot of concern on excessive use of plastics in our daily lives. In this context, uses of biodegradable plastic mulches are more pertinent. Economics of mulching, is another vital component for farmers, should also be taken into account while selecting the appropriate mulching materials. In future, similar to soil hydraulic properties, the thermal properties of different soil series should be computed to develop pedotransfer functions relating them to other easily measurable soil parameters. More laboratory studies are essentially required to understand the effect of soil with different mineralogical compositions on soil temperature in the presence of mulch. The effect of presence of various proportions of stable and other fractions of soil organic mat er in altering the soil thermal environment is another important aspect, which needs further investigations.

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