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Review

Sustainable fruit production by soil moisture conservation with different mulches: A review

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It is essential to find ways and mean to increase the yield and lessen the cost of production so that there is enough fruit production to meet the requirement of the consumers. The yearly growth of plants, excessive growth of weeds and production of fruits deplete the soil of its nutrient reserves resulting in reduction of native-soil fertility. Mulching of organic and inorganic materials create favourable conditions for getting maximum production of quality fruits on sustainable basis within the limits of soil, water and fertility management. There is a need to conserve soil moisture and reduce weed population for proper maintenance of soil moisture and fertility. Mulching is thus, one of the most important cultural practice which affects growth, yield and quality in fruit crops. Tree growth is greatly influenced by the use of different organic and inorganic mulching materials. They conserve soil moisture in the root zone of fruit trees. The presence of adequate moisture in the soil is vital for growth and physiological processes. Besides conserving moisture, mulching also prevents sudden and extreme temperature changes, reduces erosion by wind or water, checks surface run-off and suppresses the weed growth. The application of organic and inorganic mulches in fruit orchards create an additive effect by restricting the nutrient removal through weeds and ultimately creating favourable conditions for availability of nutrients for getting higher productivity of good quality fruits on sustainable basis.

Key words: Mulching, growth, fruit quality, yield, moisture conservation, weed control.

INTRODUCTION

Mulching is the process of covering the soil surface around the plants with an organic or synthetic material to create congenial condition for the plant growth, development and efficient production. Mulch is any material applied to the soil surface for protection or improvement of the covered area. Mulch is a protective layer of either organic or inorganic material that is spread on the topsoil and is divide into two categories based on type of mulch used that is, organic mulch and inorganic mulch.

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Organic mulches add nutrients and humus to the soil as they decompose, improving its tilth and moisture holding capacity while, inorganic mulches are inert materials that have not originated from living material, they do not add nutrients and humus to the soil. The practice of mulching in fruit trees impart manifold beneficial effect, like stabilization of soil temperature, reduced water loss through evaporation, resulting more stored soil moisture (Shirgure et al., 2003), maintenance of soil fertility (Kotze and Joubert, 1992; Thakur et al., 1997), suppression of weed growth (Bhutani et al., 1994; Kaur and Kaundal, 2009; Sharma and Kathiravan, 2009), improvement in growth and yield (Khokhar et al., 2001; Sharma, 2004; Pande, 2005), reduces erosion by wind or water, checks surface run-off and suppress the weed growth (Merwin et al., 1994).

Tree growth is greatly influenced by the use of different organic and inorganic mulch materials. They conserve soil moisture in the root zone of the fruit trees. The presence of adequate moisture in the root is vital for plant growth and physiological processes. Mulches retain moisture and also add organic matter into the soil and reported to increase fruit quality to a great extent. Mulching is a beneficial practice to obtain higher income from orchards (Prakash et al., 2007) and results in higher yield (Patra et al., 2004). Mulching with organic wastes has been found very effective for establishment of aonla orchard (Rao and Pathak, 1998; Singh et al., 2009). Mulching encourages the proliferation of feeder roots resulting in efficient uptake of plant nutrient. Various mulches in aonla orchard in sodic soil were found better with paddy straw, sugarcane trash, coconut husk and farm yard manure (Rao and Pathak, 1996).

The addition of organic material to the soil is generally known to influence some of the soils physical, chemical and biological aspects (Trisdal, 1989). Of these, the improvement of soil physical aspects such as texture and structure are seen as the main benefits of organic amendments, as the mineral content of organic materials is known to be low (Shiralipour et al., 1992). When these organic materials are mechanically incorporated into the soil, it is known to enhance the soil biological aspects in various ways (Dick, 1992). These include, increased mineralization rates, a suppression of some diseases and nutrient cycling (Pinamonti, 1998). Studies indicate that the addition of organic mulches decreased the fertilizer requirements (Evanylo et al., 2008), decreased soil bulk density, and increased soil carbon and cation exchange capacity (Tiquia et al., 2002), as well as improved soil structure (Pinamonti et al., 1995).

Temperature regulation is achieved by mulching layer buffering in the soil layers from direct radiation and thereby reducing the evaporation of soil water (Haynes, 1980). This would allow the roots to grow into the upper soil layers to form a feeding zone of fine roots in an environment rich in oxygen (Trisdal, 1989). This increases the crop's potential to absorb any additional fertilizer amendments and ensures effective use of fertilizers in order to meet crop demand and produce high quality crops.

As such conservation of soil moisture is imperative owing to meager and costly irrigation facilities. Mulching is known to play an important role in the conservation of soil moisture (Hira et al., 2003) during dry periods besides offering the advantages water runoff and soil erosion, improve water and fertilizer use efficiency (Salaria, 2009). Moreover, it keeps the soil warm in winter and cool in summer (Ramakrishna et al., 2006). Mulching has been found to be an effective method for increasing the yield of tropical, sub-tropical and temperate fruit crops on sustainable basis. Keeping in view the immense importance of mulching, this review presents various scenarios related to effects of organic and inorganic mulching materials on various parameters of growth, yield and quality of fruit crops.

ROLE OF MULCHING ON SOIL CHARACTERISTICS

Soil water

A major factor in apple quality is fruit size. Since, fruit size is greatly influenced by water deficit, it is recommended that water supply be optimized to enhance the number of large fruit (Naor et al., 1997). On soils where herbicides are used to control the weeds, a crust may form on the bare surface. This crust may cause low infiltration of water and high runoff rates. When these bare soils are on a slope, runoff can cause erosion (Trisdal, 1989). Organic mulches can reduce the impact of raindrops on surface sealing and thereby increase the infiltration tempo. This way erosion is reduced by the increased water infiltration rate and the decrease in runoff velocity (Smets et al., 2008). In frequently tilled soils, initial water infiltration is high in the loose soil. Thereafter, it is restricted by the subsoil with small pores. Further infiltration rates will then be controlled by the subsoil. Crusts tend to form in the subsoil when upper soils are tilled extensively. This will restrict penetration by water and roots (Trisdal, 1989). In contrast, simple mulches such as straw has shown to increase soil aggregate stability, which improved the soil permeability for water penetration and aeration to the deeper layers (Pinamonti et al., 1995). Organic mulches, such as straw, have further shown to increase the amount of available water in the soil (Trisdal, 1989), by reducing evaporation from the soil surface (Pinamonti et al., 1995). This will reduce moisture stress between irrigations and can even increase irrigation intervals (Baxter, 1970).

In addition, the availability of water in the surface layers, which are prone to drought conditions, would enable root to utilize this area and effectively increase the root zone (Trisdal, 1989; Pinamonti et al., 1995). Accordingly, Wooldridge (1992) announced that, straw

mulch applied on ridges in a pear orchard expanded irrigation intervals with more than double, compared to herbicide control, causing a 45% decrease in the total amount of water used for irrigation through the season. Furthermore, Trisdal (1989) indicated that weeds can also be controlled effectively with organic mulches. Weed control is important since they are able to compete for water and minerals within the same root zone as the crop (Brown and Tworkoski, 2004). However, the thickness of the mulch will strongly influence the abundance of weeds present (Walsh et al., 1996). Accordingly, green mulches have also shown to reduce crop yields, as they increase the total nutrient (especially N) and water demand within in the same root zone (Trisdal, 1989).

Soil temperature

Gur et al. (1972) stated that the optimum root growth temperature for several apple rootstocks seems to be near 25°C. Furthermore, they reported that increased supra optimal root temperatures of 35°C caused anaerobic respiration in the roots, with the formation of acetaldehyde and ethanol due to lack of oxygen supply. These products are transported upwards in the tree and cause damage to the leaves. Symptoms in the leaf can be detected by a decrease in chlorophyll content and the formation of intervenous necrosis. These supra-optimal root temperatures are also responsible for a decrease in the production of cytokinin in the roots. In summer, upper soil temperatures can be very high. This will have an effect on the activity of the roots and even kill some finer roots (Trisdal, 1989). Pinamonti et al. (1995) found a compost mulch to regulate the temperature of soil by reducing the daily range and creating a more constant temperature suitable for root activity. The ability of organic mulches to regulate the soil temperature is closely correlated with its ability to reduce evaporative water loss (Othieno, 1971). The combined effects of water availability and temperature regulation will increase the effective utilization of the soil surface layers for mineral uptake (Othieno, 1971; Trisdal, 1989). Mathews et al. (2002) reported that a synthetic mulch controlled evaporative water loss as effective as organic mulches, but it lacked some of the other benefits organic material in the soil. According to Glover et al. (2000), addition of organic material with mulching together with the effect of water availability in the soil will influence the soil biological aspects such as, nutrient cycling and mineralization rates which could further increase crop performance (Wooldridge, 1992).

Soil mineral content

The two main forms in which N is applied to the soil as inorganic fertilizer are ammonium (NH_4^+) and nitrate (NO_3^-). These two forms have different effects on the soil, availability of other elements and the morphology of the root system. The pH of the soil is strongly influenced by the source of N; NO_3^- causes the pH to rise, whereas NH_4^+ will cause a decrease. When N is applied entirely as NH_4^+, it causes a reduced absorbance of potassium (K), phosphorus (P), magnesium (Mg), calcium (Ca), manganese (Mn) and iron (Fe) when compared to N applied entirely as NO_3^- (Bhat, 1983). The source of N applied to apples will influence the root morphology. With NO_3^- as the only source, the plant will form long and thin roots with very little root hairs whereas NH_4^+ as the only source causes short and thick roots, covered in long thin root hairs over their entire length. NO_3^- creates roots with well spread lateral branches, whereas NH_4^+ causes roots to form clusters. The volume of soil explored by the root system can thus be greatly influenced by source of N applied. This will have an indirect effect on the absorption of other minerals (Bhat, 1983). Mulches can be made from different organic materials with variable properties. This can cause mulches to have different effects on the soil food web, as well as the mineralization of the elements such as N and P (Forge et al., 2003).

Lakatos et al. (2001) stated that nearly all the transformation of N and C from organic material is done by micro-organisms in the soil. These micro-organisms also play a significant part in the availability and transformation of minerals like Ca, Mg, P, Mn, K, Fe and zinc (Zn), and will therefore influence plant nutrition. They further revealed that application of manure mulch to the surface will increase the number of nitrification and cellulose degrading bacteria in the soil. Microbial decomposition of organic materials like animal manure or bio-solids with high amounts of N will result in a high level of N mineralization (Forge et al., 2003). Shredded paper and sawdust decomposition will result in N-immobilisation, because of the greater C:N ratio (Forge et al., 2003). However, the extend of such immobilisation is not known when these high C organic materials are applied as a mulch to irrigated orchards together with N fertilization (Forge et al., 2008).

Neilsen et al. (2003) found that N immobilisation can be overcome when the orchard was regularly fertigated together with the mulch. On coarse-textured soil, high density apple orchards under drip irrigation are likely to develop deficiency symptoms of K due to the depletion of K from the soils. The application of alfalfa mulch to such soils has shown to inhibit the tendency of K-depletion. The concentrations of Ca, K and Mg, together with root development, are increased in the upper soil layer using sawdust mulch (Szewczuk and Gudarowska, 2004). Trisdal et al. (1989) stated that the addition of organic material to soil seems to be the only practical method to increase the stability and structure of soil aggregates. When soil is frequently tilled, the organic C is removed from the soil through oxidation. Organic mulches will influence the physical properties of soil by causing an

increase in the soil organic matter, porosity and cation exchange capacity (Merwin and Brown, 2009), but decrease the bulk density in the soil (Mathews et al., 2002).

Mulching with organic material increases the aggregate stability and structure of soil (Smets et al., 2008). This will reduce erosion by wind (Walsh et al., 1996). All of these physical aspects will have an effect on the availability of nutrients to the plant and therefore influence growth (Mathews et al., 2002). Neilsen et al. (2008) stated that the increase in available mineral content of the soil associated with organic mulches, in combination with enhanced microbial activity and root development may, in part, be responsible for the improved yield and growth of apples. St. Laurent et al. (2008) compared the effects of four different ground management systems (GMS) after 14 years. The GMS were: pre-emergence herbicides; post-emergence herbicides; mowed sod grass; and bark mulch. The bark mulch increased soil moisture content, soil organic matter and mineral concentrations of Fe, Mn, Ca and P compared to the other three GMS.

Role of mulching on vegetative characteristics of fruits

Tree growth is greatly influenced by the use of different organic and inorganic mulching materials. They conserve soil moisture in the root zone of fruit trees. Water plays an important role in the growth and development of plants. The presence of adequate moisture in the soil is vital for plant growth and physiological processes. According to White and Holloway (1967) straw mulch resulted in maximum trunk girth and leaf size as compared to clean cultivation in apple orchard. Similarly, mulching has been reported to induce better growth of trees as compared to cultivation (Singh et al., 2001). Haynes (1980) observed that mulching generally increased the growth and vigour of various fruit trees.

Tree height

Shukla et al. (2000) studied the effect of various treatments of irrigation and mulching *viz*., 200 guage black polyethylene, 8 cm thick farmyard manure (FYM), paddy straw, grass, and unmulched control on growth of aonla (*Emblica officinalis*) cv. NA-7 and found that black polyethylene was the most effective inorganic mulching material and paddy straw as organic mulching material for increasing plant height (0.78 m) as compared to control (0.43 m). Bhat (2004) studied the effect of herbicide, nitrogen, potassium and orchard floor management practices on growth, yield and fruit quality of apricot (*Prunus armeniaca* L.) and reported that grass mulch significantly enhanced the tree height (34.47 cm) as compared to control (27.16 cm).

Mukherjee et al. (2004) studied the effect of water regime, mulch and kaolin on growth and yield of ber cv. Mundia and reported that black polythene mulch improved the plant height (0.78 m) as compared to control (0.53 m). Patra et al. (2004) studied the effects of mulching on the growth and fruit yield of guava cv. Sardar and reported that paddy straw mulch gave the highest increase of 0.78 m in plant height. Verma et al. (2005) studied the effects of mulching on the yield and quality of apples and obtained maximum plant height with grass mulching in combination with broadcasting and mixing of phosphorus and potassium fertilizers.

Sharma and Khokhar (2006) studied the effect of different mulches and herbicides on growth, yield and quality of strawberry (*Fragaria* x *ananassa* Duch.) cv. Chandler and observed that black polyethylene significantly increased the plant height compared to control and other mulches. Das et al. (2010) studied the response of guava cv. L-49 to soil covers and reported highest increase in plant height (0.7 m) with paddy straw mulch. Singh et al. (2010) studied the efficacy of organic mulches on soil properties, earthworm population, growth, yield and fruit quality of aonla cv. NA-7 in semi-arid ecosystem and found that plant height was significantly higher (4.87 m) in paddy straw as compared to control (4.55 m). Joshi et al. (2012) studied the effect of mulching, drip irrigation scheduling and fertilizer levels on plant growth, fruit yield and quality of litchi (*Litchi chinensis* Sonn) and found that black polyethylene mulch recorded a significant increase in plant height (4.87 m) as compared to unmulched plants (4.49 m).

Shirgure (2012) studied sustainable acid lime fruit production and soil moisture conservation with different mulches and reported highest increase in plant height (0.19 m) with black polyethylene mulch. Singh et al. (2012) studied growth and biomass of ber (*Ziziphus mauritiana*) as influenced by various soil moisture conservation techniques under rainfed condition and reported that mulching increased the plant height (243.4 cm) significantly over control (198.1 cm). Bakshi et al. (2014) while studying the effect of different mulching materials on growth, yield and quality of strawberry cv. Chandler recorded the maximum plant height of 21.67 cm under black polythene mulch whereas, it was minimum in control (16.33 cm).

Tree spread

Chattopadhyay and Patra (1992) reported that increase in plant spread were maximum (27.37 cm) under black polythene soil covering whereas it was minimum (18.15 cm) under unmulched trees of pomegranate. Shukla et al. (2000) reported that black polyethylene in aonla was the most effective inorganic mulching material and paddy straw as organic mulching material for improving canopy spread parameters. Mukherjee et al. (2004) reported that

black polythene mulch improved plant spread (26.03 m) in ber cv. Mundia as compared to control (16.23 m). Patra et al. (2004) reported that paddy straw mulch in guava cv. Sardar gave the highest increase in plant spread of 0.87 m in east-west and 0.85 m in north-south directions. Verma et al. (2005) reported highest plant spread in apples with grass mulching incombination with broadcasting and mixing of phosphorus and potassium fertilizers.

Das et al. (2010) reported maximum increase in canopy spread of 0.76 m in east-west and 0.74 m in north-south directions with paddy straw mulch. Singh et al. (2010) reported highest increase in plant spread (east-west 3.35 m and north-south 3.20 m directions) with paddy straw mulch as compared to control in aonla cv. NA-7. Joshi et al. (2012) observed significant increase in plant spread (4.96 m) under black polyethylene mulch as compared to unmulched (4.53 m) in litchi. Singh et al. (2012) studied growth and biomass of ber (*Ziziphus mauritiana*) as influenced by various soil moisture conservation techniques under rainfed condition and observed that mulching increased the canopy spread of 256.1 cm significantly over unmulched plants (198.6 cm). Khan et al. (2013) studied the effect of growth, yield and nutrient uptake of guava (*Psidium guavaja* L.) affected by soil metric potential, fertigation and mulching under drip irrigation and reported maximum canopy spread of 5.53 m in east-west and 5.0 m in north-south directions with mulching whereas, it was minimum (5.35 m) in east-west and (4.80 m) in north-south directions in unmulched plants. Bakshi et al. (2014) reported maximum plant spread of 31.24 cm under black polythene mulch in strawberry as compared to control (26.61 cm).

Tree volume

Hieke et al. (1997) found that plastic soil mulch and cloche mulch increased canopy volume of peach by 47 and 23%, respectively as compared with control under the sub-tropical Australian conditions. Shirgure et al. (2003) reported that canopy volume of Nagpur mandarin (*Citrus reticulata)* was significantly higher using black polythene mulch (8.67 m^3) followed by mulching with local grass (7.37 m^3) as compared to control (6.05 m^3). Bhat (2004) reported that grass mulch in apricot recorded maximum tree volume of 31.23 m^3 as compared to pine needles mulch (29.52 m^3), black polythene mulch (28.86 m^3), bicoloured polythene mulch (28.42 m^3) and control (26.52 m^3). Bal and Singh (2011) while studying the effect of mulching in ber, obtained maximum tree volume of 45.13 m^3 under black polythene incombination with gramoxone treatment followed by 44.18 m^3 under black polythene incombination with glyphosate as compared to 33.04 m^3 under control. Joshi et al. (2012) observed significant increase in tree volume (43.47 m^3) under black polyethylene mulch as compared to unmulched control (31.09 m^3) in litchi. Shirgure (2012) reported that black polyethylene significantly increased volume of acid lime plants (2.30 m^3) as compared to control (1.50 m^3).

Role of mulching on yield attributes

Fruit set

Robinson and O' Kennedy (1978) observed highest fruit set in apple cv. Golden delicious with grass mulch and the lowest with overall herbicides plus straw mulch treatments. Albregts and Chandler (1993) observed remarkable increase in number of fruits per plant in strawberry under plastic mulch as compared to control. Jagtap and Wachal (1993) recorded maximum fruit set under saw dust (5.09 %) followed by wheat straw mulch (4.34 %) and sugarcane trash mulch (4.30 %). Mandal and Chattopadhyay (1994) observed maximum fruit set per plant in custard apple with black polythene mulch followed by straw mulch and minimum with control. Bhat (2004) reported maximum fruit set in apricot cv. New Castle under grass mulch (62.61 %) and least in control (43.15 %). Pande et al. (2005) studied the effect of various mulches on growth, yield and quality attributes of apple cv. Red Delicious and found maximum fruit set (33.86 %) under dry grass mulch as compared to other mulching materials and that of control. Rui (2005) while studying the effects of mulching on flowering and fruit set in sweet cherry (*Prunus avium*) cv. Hongdeng, reported maximum fruit set of 28.01 % with plastic mulching. Das et al. (2010) reported highest fruit set of 82.15 % in guava cv. L-49 with paddy straw mulch whereas it was lowest in control (73.14). Banik et al. (2011) while studying the effect of different irrigation intervals in combination with mulching treatments in mango found highest number of fruits per panicle (16.30 %) under 30 days irrigation interval incombination with dry leaves organic mulching followed by 9.60 % under 20 days irrigation interval incombination with dry leaves organic mulching and lowest number of fruits per panicle (7.30 %) were observed in control.

Fruit drop

Patil et al. (2002) studied the effect of growth regulators and mulching on fruit drop of Nagpur mandarin and reported minimum fruit drop of 85.10 % in plants treated with NAA 30 ppm incombination with dry grass mulch while maximum fruit drop of 96.04% was observed in control. Ghosh and Bauri (2003) reported that the fruit retention of mango cv. Himsagar grown in rain fed soils was significantly higher with the application of black polythene mulch (68.0 %) than paddy straw mulch (63.0%) and control (45.3 %). Pande et al. (2005) studied the effect of various mulches on growth, yield and quality

attributes of apple and reported minimum fruit drop (37.39 %) with dry grass mulch and maximum fruit drop (51.52 %) under control. Das et al. (2010) reported highest fruit drop (45.76 %) in guava cv. L-49 under unmulched and least (36.03 %) in paddy straw mulch.

Yield

Badiyala and Aggarwal (1981) noted the effect of mulching on strawberry production and observed significant increase in yield of 68% under polythene and 33% under pine needle mulching treatments over the control. Mage (1982) obtained significantly higher yield of apple under the black polythene mulch than control. Chattopadhyay and Patra (1992) recorded higher yield of pomegranate under black polythene soil cover followed by saw dust, banana trash and control. Jagtap and Wachal (1993) reported maximum yield under sugarcane trash mulch compared with control in ber. Kaundal et al. (1995) recorded highest fruit yield of peach cv. Shan-i-Punjab under black polythene mulch (58 kg/tree) followed by glyphosate at the rate of 2.5 l/ha (52 kg/tree) and control (42 kg/tree). Reddy and Khan (1998) recorded the maximum yield of sapota cv. Kalipatti under 200 guage black polythene film (134.6 kg/tree) compared with 400 guage black polythene film (128.6 kg/tree) and control (78 kg/tree).

Borthakur and Bhattacharyya (1999) observed the effect of mulching on yield and mineral composition of guava and found significantly higher yield under paddy husk (13.6 kg/tree) as compared to control (8.7 kg/tree). Kumar et al. (1999) recorded highest fruit yield in apple cv. Starking Delicious under herbicide incombination with mulching of hay followed by 10 cm hay mulching and white netted polythene mulch. Shukla et al. (2000) studied the effect of mulching on plant growth and leaf nutrient status of aonla and recorded higher yield as compared to control. Singh et al. (2002) obtained significantly higher fruit yield of apricot cv. new castle under drip irrigation in combination with black plastic mulch as compared to drip irrigation.

Black polythene mulch significantly increased fruit yield of mango cv. Himsagar than control (Gosh and Bauri, 2003). Shirgure et al. (2003) studied the effect of different mulches on soil moisture conservation, weed reduction, growth and yield of drip irrigated Nagpur mandarin and observed highest yield under black polythene mulch (73.7 kg/tree) followed by grass mulch (69.7 kg/tree). Patra et al. (2004) studied the effects of mulching on the growth and fruit yield of guava cv. Sardar and reported that the plants under black polythene mulch produced maximum yield (44.32 kg/plant and 12.32 t/ha). Das et al. (2007) studied the effect of different mulching materials on strawberry and found that black polyethylene produced maximum yield in comparison to paddy straw. Kumar et al. (2008) during a five year study with 'Lal Sundari' mango (*Mangifera indica* L.) found higher yields under dry grass mulching. Ghosh et al. (2009) reported that mulching of plant basin and watering in dry period significantly improved the yield of sweet orange (*Citrus sinensis*) cv. Mosambi.

Castaneda et al. (2009) recorded maximum fruit yield of 386.66 g/plant in strawberry under black plastic polyethylene mulch followed by 292.14 g under black propylene mulch and the minimum yield of 40.28 g per plant under white propylene film mulch. Sharma and Kathiravan (2009) during a two year study with plum cv. Santa Rosa recorded significantly higher mean fruit yield of 80.62 quintal ha^{-1} in black polythene mulched trees. Kher et al. (2010) reported significantly higher fruit yield in strawberry cv. Chandler under black polyethylene mulch followed by transparent polyethylene and paddy straw mulch. Singh et al. (2010) reported maximum fruit yield in aonla cv. NA-7 with paddy straw (41.50 kg/plant) followed by maize straw (40.0 kg/plant) as compared to control (37.50 kg/plant). Bal and Singh (2011) obtained highest fruit yield of ber (45.36 kg/tree) under black polythene mulch treatment and least yield of 25.23 kg/tree in control. Kumar et al. (2012) while studying the impact of different mulching materials on growth, yield and quality of strawberry reported significantly higher fruit yield under transparent polyethylene mulch followed by black polyethylene mulch while it was minimum in control.

Role of mulching on physical characteristics of fruits

Fruit weight

The fruit weight of Coorg mandarin was highest (109.7 g) in mulch treatment and was minimum (96.5 g) in shade treatment (Mustaffa, 1989). The significantly higher fruit weight of 79 g in peach cv. Shan-i-Punjab was recorded under black polythene mulch as compared to 63 g in control (Kaundal et al., 1995). Hieke et al. (1997) found maximum fruit weight of 95.3 g in peach cv. Florida Prince under plastic soil mulch as compared to 73.2 g in control. Kumar et al. (1999) reported the highest fruit weight of 260.4 g in apple cv. Starking Delicious under the treatment of herbicide incombination with mulching of hay followed by mulching with white netted polythene (245.5 g).

The fruit weight of apricot cv. New Castle was significantly higher under drip irrigation incombination with plastic mulch as compared to control (Singh et al., 2002). Gosh and Bauri (2003) observed that fruit weight of mango was highest in the treatment of black polythene mulching (322 g) followed by hoeing of tree basin (321 g) and paddy straw mulch (317 g), while it was the lowest in control (288 g). The highest fruit weight of 140.5 g was observed in Nagpur mandarin under black polythene mulch followed by 135.5 g under grass mulching, 135 g under white polythene and 133 g under paddy straw mulching (Shirgure et al., 2003).

Mukherjee et al. (2004) reported that fruit weight of ber

cv. Mundia was significantly higher under the black polythene mulching as compared to control. Ali and Gaur (2007) observed the highest fruit weight of 7.94 g in strawberry under black polythene mulch followed by 7.73 g in paddy straw and sugarcane trash mulch and 7.28 g in control. Maji and Das (2008) studied the improvement of fruit quality and yield of guava cv. L-49 under different organic and inorganic mulching materials and reported maximum average fruit weight of 117.38 g under mulching with sugarcane trash, followed by 98.80 g under paddy straw mulch. Singh et al. (2010) reported maximum fruit weight in aonla cv. NA-7 under paddy straw (43.16 g) followed by grass mulch (41.15 g) and maize straw mulch (41.15 g) as compared to control (39.0 g). Bal and Singh (2011) reported maximum fruit weight in ber under black polythene (22.5 g) closely followed by black polythene incombination with gramoxone (22.3 g) treatments. Bakshi et al. (2014) recorded maximum fruit weight of 11.83 g under black polythene mulch in strawberry cv. Chandler whereas, it was minimum in control (8.16 g).

Fruit size

Gosh (1985) obtained large sized and juicy fruits with grass mulching in sweet lime. Mustaffa (1989) studied the effect of mulching and shade on yield, quality and leaf nutrient composition of Coorg mandarin and observed maximum fruit length (5.68 cm) and fruit breadth (5.96 cm) under dry leaf mulch treatment as compared to control. Gupta and Acharya (1993) while studying the effect of mulch induced hydrothermal regime on root growth, water use efficiency, yield and quality of strawberry found that berry size was significantly higher under black polyethylene followed by pine needle mulch. Neilsen et al. (2003) studied the effect of mulches and bio-solids on vigour, yield and leaf nutrition of fertigated high density apple and found that larger fruit size was obtained on trees mulched with alfa-alfa hay. Agrawal et al. (2005) reported that fruit length and width of mango cv. Dashehari was significantly higher under drip irrigation incombination with plastic mulch treatment as compared to control. Pande et al. (2005) studied the effect of various mulches on growth, yield and quality attributes of apple cv. Red Delicious and found maximum fruit size under dry grass mulching closely followed by dry leaf mulch, while the minimum fruit size was recorded under clean cultivation. Sharma and Khokhar (2006) studied the effect of different mulches and herbicides on growth, yield and quality of strawberry (*Fragaria* x *ananassa* Duch.) cv. Chandler and found maximum fruit size (length x breadth) under black polyethylene mulch followed by bicoloured polyethylene.

Castaneda et al. (2009) while studying the utilization of different mulching types in strawberry production found that black polyethylene film mulch increased the fruit size as compared to white polyethylene mulch. Singh et al. (2010) reported that fruit length in aonla cv. NA-7 was significantly higher in grass mulch (4.05 cm) followed by paddy straw (4.00 cm) as compared to 3.70 cm in control. Bal and Singh (2011) while studying the effect of mulching in ber recorded maximum fruit length (4.37 cm) and fruit breadth (3.21 cm) under black polythene mulch whereas minimum fruit length of 2.34 cm and fruit breadth of 2.16 cm was observed in control. Bakshi et al. (2014) recorded maximum fruit length of 3.93 cm and fruit breadth of 3.16 cm in strawberry cv. Chandler under black polythene mulch whereas minimum fruit length of 3.00 cm and fruit breadth of 2.00 cm was observed in control.

Fruit volume

Gaikwad et al. (2004) recorded significantly higher average fruit volume in Nagpur mandarin fruits under grass mulch followed by polyethylene mulch. Pande et al. (2005) reported significantly higher fruit volume in apple under organic mulching materials as compared to control. Kher et al. (2010) while studying the effect of different mulching material in strawberry reported significantly higher fruit volume under black polyethylene and minimum in control.

Specific gravity

Specific gravity varies both in ultimate magnitude and in rate of seasonal change in aonla, but generally shows a decrease from early season to maturity. Changes in specific gravity of fruits during growth are due to increases in intercellular and capillary air spaces. Thus, fruit density reflects the extent of air spaces, the amount of lignification (stone cells), and the density of fruit cells. It is true for all kinds of fruit that smaller ones are denser than larger ones, both during the season and at harvest (Westwood, 1993). Kumar et al. (2012) reported significantly higher specific gravity of 0.97 in white polyethylene in strawberry followed by 0.96 in black polyethylene and 0.95 in pine needles as compared to 0.94 in control.

Pulp: stone ratio

Kumar et al. (2008) studied the effect of organic mulching and irrigation schedule through drip on growth and yield of ‘Lal Sundari’ mango (*Mangifera indica* L.) in eastern region of India and recorded maximum pulp weight at maturity stage under organic mulching incombination with drip irrigation at 75% pan Evaporation Replenishment (ER), but it remained at par with other treatments *viz*., organic mulch incombination with 25% ER, organic mulch

incombination with 50 per cent ER, organic mulch and control. They also reported that maximum stone weight was recorded under rainfed control.

Role of mulching on quality characteristics of fruits

Total soluble solids (TSS)

Badiyala and Aggarwal (1981) noted the effect of mulching on strawberry production and observed that percentage of TSS was highest under black polythene mulch, which was 1.10 and 1.22 times more than that under pine needle and control, respectively. Mustaffa (1989) observed maximum TSS content of 11.0% in Coorg mandarin under dry leaf treatment and minimum in control (10.8 %). Kaundal et al. (1995) reported significantly higher TSS content of 13.0 % in peach cv. Shan-i-Punjab under black polythene mulch as compared to 10.6 % in control. Gupta and Acharya (1993), while studying the effect of mulch induced hydrothermal regime on root growth, water use efficiency, yield and quality of strawberry found that black polyethylene mulching resulted in higher TSS as compared with the remaining mulched treatments.

Ghosh and Bauri (2003) reported highest TSS of 18.3 % in mango under black polyethylene mulch followed by 17.2 % in paddy straw and lowest TSS of 14.31 % in fruits of untreated trees. Gaikwad et al. (2004) observed highest TSS under dry grass mulch in Nagpur mandarin followed by polyethylene mulch while it was least under control. Pande et al. (2005) while studying the effect of various mulches on growth, yield and quality attributes of apple cv. Red Delicious found that application of organic mulches gave relatively low TSS (13.7°Brix) content than black polyethylene mulch which recorded a TSS content of 14.2°Brix. Sharma and Khokhar (2006) studied the effect of different mulches and herbicides on growth, yield and quality of strawberry (*Fragaria* x *ananassa* Duch.) cv. Chandler reported that black polyethylene significantly increased the TSS (8.95 and 8.88%) followed by bicoloured polyethylene (8.65 and 8.68%) during both the years of study.

Kim et al. (2008) studied the effect of pre harvest reflective mulch on growth and fruit quality of plum (*Prunus domestica* L.) and observed that TSS was higher by 0.3°Brix in the mulching treatment applied 2 and 3 weeks before harvesting compared to control. Kumar et al. (2008) studied the effect of organic mulching and irrigation schedule through drip on growth and yield of 'Lal Sundari' mango (*Mangifera indica* L.) in eastern region of India observed maximum TSS under organic mulching incombination with drip irrigation at 25% pan Evaporation replenishment (ER) which remained at par with other treatments *viz*., organic mulch incombination with 50% ER, organic mulch incombination with 75% ER, organic mulch and control.

Kaur and Kaundal (2009) studied the efficiency of herbicides, mulching and sod cover on control of weeds in plum orchard and observed that black polyethylene increased the TSS over other treatments and lowest TSS content was recorded in control. Singh et al. (2010) reported that paddy straw mulch in aonla cv. NA-7 recorded the maximum TSS of 8.25% followed by 8.15% in grass mulch and 8.10% in maize straw mulch as compared to 7.85% in control. Bal and Singh (2011) while studying the effect of mulching material in ber observed that maximum TSS of 12.16 % was recorded with black polyethylene incombination with gramaxone (1 litre/ha). They also reported that TSS under paddy straw and sarkanda was higher as compared to control. Kumar et al. (2012) recorded significantly higher TSS in strawberry under transparent polyethylene mulch followed by black polyethylene. They also reported higher TSS under organic mulches. Bakshi et al. (2014) while studying the effect of mulching in strawberry cv. Chandler recorded highest TSS of 7.63^{0}B under black polythene mulch whereas, it was found lower in control (6.67^{0}B).

Titratable acidity

Ghosh and Bauri (2003) while studying the impact of various mulches in mango found that fruit acidity was not influenced by various mulching treatments. Hassan et al. (2000) studied the effect of different mulches on the yield and quality of strawberry cv. Oso Grande and observed minimum acid content in the fruits harvested from plants under black polythene mulch (1.13 %) and maximum in control (1.33 %). However, Gaikwad et al. (2004) while studying the effect of different mulches on soil moisture, and soil temperature in Nagpur mandarin found non-significant effect of different mulching treatments on acidity. Pande et al. (2005) found higher titratable acidity of 0.25% in apple cv. Red Delicious grown under dry grass mulch followed by 0.20% acid content recorded under black polyethylene and least acid content of 0.19% was recorded under clean cultivation.

Kim et al. (2008) studied the effect of preharvest reflective mulch on growth and fruit quality of plum (*Prunus domestica* L.) and observed that fruit acidity was decreased by reflective film mulching. Kaur and Kaundal (2009) studied the efficacy of herbicides, mulching and sod cover on control of weeds in plum orchard and reported that black polyethylene mulch was found to be most effective treatment in reducing the acid content of plum fruits followed by different doses of glyphosate and diuron which were equally effective in lowering the acid content of plum fruits. Singh et al. (2010) reported maximum acidity of 2.70% under grass mulch and minimum titratable acidity of 1.98% with paddy straw mulch.

Bal and Singh (2011) while studying the effect of mulching material in ber recorded highest titratable

acidity under control whereas least was observed under paddy straw mulch. Kumar et al. (2012) recorded significantly higher fruit acidity in strawberry under transparent polyethylene followed by black polyethylene. The minimum fruit acidity was obtained under control. Melgarejo et al. (2012) reported that organic acids content were slightly higher in plums from trees treated with plastic mulching film. Bakshi et al. (2014) recorded highest acidity of 0.80% under control whereas, least acidity of 0.64% was found under black polythene mulch in strawberry cv. Chandler.

TSS: acid ratio

Pande et al. (2005) while studying the effect of various mulches in apple crop found maximum TSS: acid ratio of 70.8 under black polyethylene as compared to TSS: acid ratio of 55.3, 62.4 and 62.5, respectively under dry grass, pine needle and dry leave mulches. Sharma and Khokhar (2006) in a two year study on the effect of different mulches and herbicides on growth, yield and quality of strawberry cv. Chandler reported highest TSS: acid ratio (10.97 and 10.93) under black polyethylene followed by bicoloured polyethylene (10.55 and 10.44) while as lowest (8.79 and 8.89) was observed under herbicide atrazine (1.0 kg/ha) treatment during both the years of study.

Sugars

Pande et al. (2005) while studying the effect of various mulches in apple cv. Red Delicious recorded highest total sugars (9.50%) and reducing sugar (6.90%) under black polyethylene mulch followed by dry leaves mulch and clean cultivation while as least was recorded under pine needle mulch. Sharma and Khokhar (2006) in a two year study on the effect of different mulches and herbicides on growth, yield and quality of strawberry cv. Chandler reported that black polyethylene significantly improved the total sugar (7.56 and 7.60%) content followed by bicoloured polyethylene (7.31 and 7.41%) while as least values (6.67 and 6.57%) were observed under herbicide atrazine (1.0 kg ha^{-1}) during both the years of study. Das et al. (2010) while studying the effect of soil covers on guava cv. L-49 reported maximum total sugar (6.53%), reducing sugar (3.80%) and non-reducing sugar (2.72%) under paddy straw mulch as compared to other mulches and control.

Patil (2011) reported highest total sugar (6.21%) under paddy straw mulch, reducing sugar (5.38%) under black polythene mulch and non-reducing sugar (1.22%) under paddy straw mulch and least under control. Kumar et al. (2012) recorded significantly higher total sugars in strawberry under transparent polyethylene mulching followed by black polyethylene. Melgarejo et al. (2012) reported that total sugars were slightly higher in plums fruits from trees treated with plastic mulching film. Bakshi et al. (2014) stated maximum total sugar of 7.00% under black polythene mulch and minimum (6.10%) in control in strawberry cv. Chandler.

Vitamin C

Mustaffa (1989) observed that ascorbic acid content was maximum in Coorg mandarin under control (58.6 mg/100 g) followed by dry leaf mulch (57.5 mg/100 g) and was significantly higher than shade (48.8 mg/100 g). The highest ascorbic acid content of Assam lemon was recorded under paddy straw followed by water-hyacinth and lowest value was obtained in control (Nath and Sharma, 1994). Maji and Das (2008) studied the improvement of fruit quality and yield of guava cv. L-49 under different organic and inorganic mulching materials and reported the highest vitamin-C content of 189.79 mg/100 g fruit pulp, with black polythene mulch. Singh et al. (2010) studied the influence of different organic mulches on soil properties, earthworm population, growth, yield and fruit quality of aonla cv. NA-7 and reported maximum vitamin-C content with paddy straw mulch (498.00 mg/100 g) followed by maize straw (494.15 mg/100 g) and grass mulch (493.00 mg/100 g). Bal and Singh (2011) studied the effect of mulching material and herbicides on tree growth, yield and fruit quality of ber and reported maximum vitamin-C in fruits from plants mulched with black polythene (107.25 mg/100 g pulp), black polythene incombination with (1 l/ha) gramaxone (101.20 mg/100 g pulp) and black polythene incombination with (1 l/ha) glyphosate (99.76 mg/100 g pulp).

Role of mulching on weed control

Guleria (1986) reported that polyethylene film mulch decreased weed population in apple orchards to a considerable extent. Mulching has been reported to give better suppression of weed growth than other soil management systems (Robinson, 1983; Borthakur and Bhattacharya, 1992). Sharma and Bhutani (1998) observed excellent weed control in peach orchard with 10 cm thick grass mulch. Stapleton et al. (1989), Brar et al. (1992) and Buban et al. (1995) found black plastic mulch to be best suited for weed control without detrimental effect on tree growth and production as compared to herbicides, hand hoeing and soil coverings of pine needle, pine bark, livestock manure or mushroom compost.

Hartley et al. (1996) observed the effect of four organic mulches *viz*., saw dust, barley straw, compost and wool dust on the fruit yield and weed control in apple, and reported that barley straw was most effective treatment

for controlling weed growth. Rao and Pathak (1998) studied the effect of different mulches on weed growth in aonla orchard and observed minimum weed population of 9.16/m^2 under black polythene mulch followed by 74.48/m^2 in grass mulch, 77.44/m^2 in paddy straw mulch, 128.08/m^2 in rice husk and 143.08/m^2 in control after 240 days of mulching. Rana (1998) found mulching treatments to be more effective in suppressing weed growth than the herbicide treatments in apple nursery over a period of 6-7 months. Bhat (2004) studied the effect of herbicide, N, K and orchard floor management practices on growth, yield and fruit quality of apricot cv. New Castle and minimum weed population of 11/ m^2 was recorded under black polythene mulch followed by 22/ m^2 under bicoloured polythene mulch while maximum weed population of 200/m^2 were reported under hand weeded control.

Ramakrishna et al. (2006) studied the effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut and found that polyethylene mulch and straw mulch showed least weed infestation. They also reported that unmulched plot showed a greater diversity of weed species than the mulched plots. Sharma and Kathiravan (2009) studied the application of different mulches *viz*., transparent polyethylene, black polyethylene, bicoloured polyethylene, field grass, pine needles and control on soil hydrothermal regimes and growth of plum and reported that minimum weed growth was observed under black polyethylene and bicoloured polyethylene. Similar results were reported by Iqbal et al. (2015) in aonla cv. NA-7.

Conclusion

Mulching in organic horticultural produce has great export potential. The recent trends have shifted to integrated use of mulches with nutrients for control of weeds, maintenance of soil fertility and conservation of moisture for the sustainable production of fruit crops (organic horticulture). Painting the plastic with aluminum paint or white paint increases its reflectivity and cools tree basin resulting in better quality fruits than traditionally grown produce. The reflective properties of aluminum faced plastic interfere with the movement of aphids in orchards. Plastics transmit the warming wavelengths of the sun, but not those that allow weeds to grow. These materials result in warmer soils than black plastic, but cooler soils than clear plastics. The IT (Infrared transmitting) mulches retard the growth of weeds. Crops grown on IT mulch will develop 7 to 10 days earlier than crops grown on black plastic. Plastic mulches especially black plastic, do not break down and should never be incorporated in the soil. New photo-degradable or bio-degradable mulches have been developed, which will solve this problem of plastic removal or disposal. In first stage, the film is reduced to a fine powder, which is totally inert and physiologically harmless to plants. Nutrients requirement are manageable with available plant and animal residues resources as mulches. Thus, growing of produce with mulches will not only increase the soil properties but also gives good quality produce.

Conflict of Interests

The authors have not declared any conflict of interests.

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