EFFECT OF MULCHING ON SOIL WATER CONSERVATION AND PERFORMANCE OF KHASI MANDARIN (*CITRUS RETICULATA* BLANCO) IN MID-HILL REGIONS OF MOKOKCHUNG DISTRICT OF NAGALAND

Thesis

submitted to

NAGALAND UNIVERSITY

in partial fulfilments of requirements for the Degree of

Doctor of Philosophy

in

Soil & Water Conservation

by

ALONGBA JAMIR
Admin. No. Ph-172/15 Regn. No. 850/2019

Department of Soil & Water Conservation
School of Agricultural Sciences and Rural Development,
Nagaland University, Medziphema Campus – 797106
Nagaland

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To my beloved parents
for raising me to believe that everything is possible

NAGALAND UNIVERSITY
Medziphema Campus
School of Agricultural Sciences and Rural Development
Medziphema – 797 106, Nagaland

Dr. Manoj Dutta
Professor
Department of Soil & Water conservation

CERTIFICATE – I

This is to certify that the thesis entitled **"Effect of mulching on soil water conservation and performance of Khasi mandarin (*Citrus reticulata* Blanco) in mid-hill regions of Mokokchung district of Nagaland"** submitted to Nagaland University in partial fulfilment of the requirements for the award of degree of Doctor of Philosophy (Agriculture) in Soil & Water Conservation is the record of research work carried out by Mr. Alongba Jamir, Registration No. 850/2019 under my personal supervision and guidance.

The result of the investigation reported in the thesis has not been submitted for any other degree or diploma. The assistance of all kinds received by the student has been duly acknowledged.

Date :
Place : Medziphema

(MANOJ DUTTA)
Supervisor

NAGALAND UNIVERSITY
Medziphema Campus
School of Agricultural Sciences and Rural Development
Medziphema – 797 106, Nagaland

CERTIFICATE – II

VIVA VOCE ON THESIS OF DOCTOR OF PHILOSOPHY IN SOIL & WATER CONSERVATION

This is to certify that the thesis entitled **"Effect of mulching on soil water conservation and performance of Khasi mandarin (*Citrus reticulata* Blanco) in mid-hill regions of Mokokchung district of Nagaland"** submitted by Alongba Jamir, Admission No. Ph - 172/15 Registration No. 850/2019 to the NAGALAND UNIVERSITY in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy (Agriculture) in Soil & Water Conservation has been examined by the Advisory Board on ……………….............

The performance of the student has been found **Satisfactory/Unsatisfactory.**

Members	Signature
1. Prof. Manoj Dutta (Supervisor)	……………...
2. Prof. Dwipendra Thakuria (External examiner)	....
3. Dean, SASRD (Pro Vice Chancellor Nominee)	....

Members of Advisory committee

1. Prof. R.C. Nayak	……………….
2. Prof. A.K. Singh	……………….
3. Dr. Sanjoy Das	....
3. Prof. C.S. Maiti	…………………

Head	Dean
Department of Soil & Water Conservation	School of Agricultural Sciences and Rural Development

DECLARATION

I, Alongba Jamir, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis had not been submitted by me for any research degree in any other University/Institute.

This is being submitted to Nagaland University for the degree of Doctor of Philosophy in Soil & Water Conservation.

Date:

Place: Medziphema **(ALONGBA JAMIR)**

(MANOJ DUTTA)

Supervisor

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Date:

Place: Medziphema (ALONGBA JAMIR)

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LIST OF ABBREVIATIONS

/	:	Per
%	:	Percent
&	:	and
<	:	Less than
@	:	at the rate
>	:	More than
µ	:	Micron
µm	:	Micrometre
^{o}Brix	:	Degree Brix
^{o}C	:	Degree Celsius
Anon.	:	Anonymous
ANOVA	:	Analysis of variance
AOAC	:	Association of Official Analytical Chemists
Approx.	:	Approximate
BCR	:	Benefit Cost Ratio
cm	:	Centimeter
CRD	:	Completely Randomized Design
cv.	:	Cultivar
DMRT	:	Duncan’s Multiple Range Test
DSCO	:	District Soil & Water Conservation Officer
EC	:	Electrical conductivity
etc.	:	et cetera
et al.	:	and others
Fig.	:	Figure
FYM	:	Farm Yard Manure
G	:	Gram
ha	:	Hectare
i.e.	:	that is
Kg	:	Kilogram
IARI	:	Indian Agricultural Research Institute
ICAR	:	Indian Council of Agricultural Research

M	:	Metre
Max.	:	Maximum
Min.	:	Minimum
ML	:	Millilitre
Mm	:	Millimetre
Msl	:	Mean sea level
MT	:	Metric Ton
NS	:	Non-significant
NaOH	:	Sodium Hydroxide
SASRD	:	School of Agriculture Science and Rural Development
Nos.	:	Numbers
pH	:	Potential hydrogen
q	:	Quintal
RBD	:	Randomized Block Design
sp.	:	Species
T	:	Treatment
TA	:	Titratable acidity
TSS	:	Total Soluble Solids
Viz.	:	Namely

CHAPTER I

INTRODUCTION

INTRODUCTION

Khasi mandarin is one of the premiere citrus cultivar that has gained a commercial stature in North-East India. It is a vibrant golden yellow coloured fruit with loose smooth skin possessing more flesh and aromatic juice in comparison to the mandarin varieties with good shelf life and is labelled as the 'King of Oranges'. It has a distinctive quality and sweet tanginess, owing to which it has found a niche in the world's first food atlas. India is the world's fourth-largest orange producer. In India, citrus is cultivated over an area of about 1,055 thousand hectares with a production of 12,746 thousand metric tons and the productivity of 12.08 MT/ha (Barbora *et al.*, 2019), amongst which Mandarin orange (*Citrus reticulata* Blanco) is most common among citrus fruits grown in India followed Sweet Orange (*Citrus sinensis*) and Acid Lime (*Citrus aurantifolia*). Khasi Mandarin alone occupies nearly 41.52 % of the total area and 40.51 % of the total Citrus fruits produced under Citrus cultivation in India (Horticultural Statistics at a Glance, 2018).

The north eastern region of India is a repository of a number of citrus species. In Nagaland, the Changki valley of Mokokchung district, certain areas of Tuensang, Wokha, Dimapur district are popular for cultivation of khasi mandarin orange. The farmers of Nagaland cultivate Khasi Mandarin in an area of 6.52 thousand hectares with production of 47.33 thousand metric tons (Horticultural Statistics at a Glance, 2018).

The quality production of citrus fruits is highly dependent on the soil moisture availability. The presence of sufficient moisture in the soil plays a pivotal role for growth and physiological processes. Citrus (*Citrus sp.*) tree is an evergreen tree and consequently the sap circulation never entirely ceases and transpiration take place throughout the year and thus require good amount of water compared to the other subtropical fruits. In North

Eastern Region of India, there is increase in rainfall from the months of March and it last till the end week of October wherein highest rainfall is recorded during the months of June to September from the South-West monsoon. However, during the months of November to March the region is deprived of rainfall and thus it produces a long dry spell. With the lack of knowledge and economic resources for proper water conservation techniques and no assured irrigation in these regions, the conservation of soil moisture in the root zone of the tree canopy by application of mulches becomes an economic alternative approach, crucial for cultivation under rainfed condition for enhancing the yield, quality and thereby sustaining the orchard life (Shirgure, 2012).

Mulching is an agricultural technology in which the soil is roofed with organic and inorganic materials such as plastic mulch, leaves, straw, peat etc, placed around plants material so as to protect the soil from moisture loss, weeds and conserve the soil. Mulch reflects the sunlight which otherwise heats the soil and keeps the soil cooler and rate of evaporation is lowered. When the soil is topped by the mulch, the weeds under it is reduced or do not grow as they are deprived of light for their growth. Mulches bars the erosion of soil, since the running water or wind does not come in contact directly and avoids from washing or blowing it off. Mulches applied over the soil minimizes the rainwater run-off, and augment the amount of water that percolates into the soil. The production of fruits, excessive growth of weeds and yearly growth of plants depletes the nutrient reserves of the soil, which results in decrease of native-soil fertility.

During the dry spell application of mulches plays a significant role in conservation of soil moisture and also enhances the properties of soil *viz.*, biological, physical and chemical properties. It is a method that helps the plants in proper growth and development by providing better nutrient availability, modifying soil temperature and by better soil moisture conservation (Kher *et al.*, 2010). Mulches not only conserve soil moisture but also impart manifold beneficial effect, like reduction in water consumed (Keramat *et al.*, 2011), elimination of extreme variation of soil temperature, decrease the loss of water through evaporation, resulting in more reserved soil moisture (Shirugure *et al.*, 2003), maintenance of fertility of the soil (Slathia and Paul, 2012), improvement in growth and yield (Ban *et al.*, 2009; Chakraborty *et al.*, 2008; Shukla *et al.*, 2000) and controlling weeds and reducing nutrient removal by weeds (Ramakrishna *et al.*, 2006; Jiang *et al.*, 1997; Mostert, 1993).

Mulching of the soil by plastic polyethylene has showed its efficacy in soil moisture conservation and improving the growth, yield and enhancing the quality in various cultivars of citrus (Shirugure *et al.*, 2005; Lal *et al.*, 2003). Organic mulches derived from animal and plant materials such as hay, straw, husks, sawdust, compost, wood chips etc, are capable in decreasing of nitrates leaching, prevent erosion, enhance soil physical properties, water retention, supply organic matter and balancing the temperature, play a part in nutrient cycle, augment nitrogen balance and also step up the biological activity (Sarolia and Bhardwaj, 2012; Muhammad *et al.*, 2009). Organic mulches lower soil temperature during summer and increases during winter period which is favourable for proper growth during winter season and fruit development during summer season (Ping *et al.*, 1997). Regular application of organic mulches are helpful in improving the microbial flora, aeration of soil and soil physico-chemical properties which finally resulted in better growth and yield (Rao and Pathak, 1998).

Khasi Mandarin orchard area is close to 38.2 % of the total citrus orchards in the country, an exploit that makes the Khasi mandarin a commodity of economic importance. The crop is mainly dependent on rainfed cultivation in the region and therefore it becomes imperative to the find ways and means to hike the yield and reduce the production cost so that there is sufficient production of the fruit to meet the requirements of the consumers. Moreover, the systematic study on the effect of mulching on soil moisture conservation and performance of citrus under Nagaland condition has not been carried out. Though past research emphasized disease and pest infestation including soil nutrients availability, etc. are major factors of citrus decline, the past research often ignored the factor of soil moisture stress during dry spells of every year from November to March. This period is extremely important for citrus plants as flower setting to fruit setting happens in this phase. Besides, hilly farmers are resource poor and they cannot invest huge capital for micro-irrigation in existing citrus orchards. Therefore, low cost alternatives like organic mulch suitable for organic farming practices as well as who can take care of soil nutrient availability and organic carbon build-up is the need of hour. Keeping in view and taking all these into consideration the present investigation entitled **“Effect of mulching on soil water conservation and performance of Khasi mandarin (*Citrus reticulata* Blanco) in mid-hill regions of Mokokchung district of Nagaland”** was conducted with the following objectives.

1. To study the effect of mulching on soil water dynamics, soil temperature and soil properties.
2. To evaluate the effect of different mulching materials on yield and yield attributes.
3. To evaluate the cost benefit ratio of various mulching treatments.

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Mulching influences crop growth and yields by changing soil moisture removal patterns over the growing season. Soil properties and environment determine the rate of water movement in liquid and gaseous form into and out of soil. To understand how mulching changes soil moisture, soil properties affecting moisture need to be understood. Mulching is among the important factors affecting soil properties and crop yield.

The available literatures pertaining to the present investigation have been reviewed under the following heads:

2.1. Effect of mulching on temperature and soil water conservation

An experiment was done at Pantnagar to study the effect of different mulches on soil temperature and moisture in winter Tomato. Polyethylene mulch with different colours like black, blue, transparent and organic mulches like Sugarcane trash mulch and Paddy straw significantly increased the soil moisture content compared to the control. (Kumar and Srivastava, 1997).

Sharma *et al*. (2000) worked on effect of different orchard floor management practices on weed population, yield, soil moisture and temperature of Almond orchard and reported the highest soil moisture contents was observed in pine leaves mulch, while the lowest soil moisture content was recorded in grass mulch.

Mulches provide several advantages over a bare-ground orchard floor because they conserve soil moisture which may also lessen cold injury during droughty conditions (Smith, 2000).

Thakur *et al*. (2000) observed that different mulching materials such as grass, Lantana leaves and plastic, helped Bell Pepper (*C. annuum cv*. California Wonder) to perform better at water deficits from 25 to 75 % and plastic mulch had highest water use efficiency. Hatfield *et al*. (2001) reported a 34-50 percent reduction in soil water evaporation as a result of crop residue mulching.

Shirgure *et al.* (2003) investigated on the effect of different mulches on soil moisture conservation, weed reduction, growth and yield of drip irrigated Nagpur mandarin (*Citrus reticulata*) with 2 polyethylene mulches, *viz.,* black and white, of 100 µ and 3 organic mulches, *viz.,* Soybean [*Glycine max* (L.) Merr.] straw, Paddy *(Oryza sativa* L.) straw and local grasses on conservation of soil moisture, weed population, increase in growth, yield and fruit quality of Nagpur mandarin and observed that the soil-moisture conservation was higher in black polyethylene 100 µ (4.33 %), followed by grass mulching (3.0 %). The better soil-moisture conservation and weed reduction could be achieved with black polyethylene 100 µ mulch and grass mulching @ 3 tonnes/ha besides the growth, yield and fruit quality improvement of drip irrigated Nagpur mandarin in Central India.

Faber *et al.* (2003) conducted an experiment entitled "Effects of mulch on Avocado and Citrus" and recorded that there was a pronounced effect of mulches on soil moisture (reduced evaporative loss) and soil moisture tension was consistently higher in unmulched plots at all trial sites. Singh (2005) also reported that higher soil temperature (2-3 ºC above the control) and soil moisture (43.70-62.50 % higher than control) were found in polythene mulches.

Downer and Faber (2005) studied that the mulch treatments increased soil moisture retention as compared to unmulched treatments and also mulches maintained lower surface temperature than unmulched soils.

In general, the effect of mulching on the temperature regime of soil varies depending on capacity of the mulch materials to reflect and transmit solar energy and at night, condensation on the underside of the mulch absorbs the long wave radiation emitted by the soil thereby slowing cooling of the soil (Lamont, 2005). Polythene mulching has proved its effectiveness in conserving the soil moisture in Citrus (Shirgure *et al*., 2005).

Cook *et al.* (2006) reported that mulch modified the soil water balance, by adversely affecting soil water content beneath thicker application. Mulching had a beneficial effect on soil water and temperature regimes. These findings are important for identifying mulching practices for dryland agriculture and under scenarios of climatic change that predict lower rainfall and higher temperatures in summer.

On-farm trials were conducted in northern Vietnam to study the impact of mulch treatments and explore economically feasible and eco-friendly mulching options. The effect of three mulching materials (polythene, rice straw and chemical) on weed infestation, soil temperature, soil moisture and pod yield were studied. Different mulching materials showed different effects on soil temperature. Polythene mulch increased the soil temperature by about 6 ºC at 5 cm depth and by 4 ºC at 10 cm depth. No significant differences in soil temperature were recorded among polythene and straw mulch treatments at both the soil depths. Mulches prevent soil water evaporation retaining soil moisture, thus higher moisture content was always observed in the 0-60 cm soil layer of the mulched plots compared to that of the unmulched plots (Ramakrishna *et al*., 2006).

Rita *et al.* (2006) carried out an experiment on the effect of mulching and tillage on the water and temperature regimes of soil. Experimental findings and modeling recorded that mulching decreased soil water loss on an average by 0.39 mm d^{-1}. Volumetric soil water contents at pF 1, 1.8 and 2.5 up to 30 cm depth were highest (0.418, 0.390, and 0.360 m^3 m^{-3}, respectively) with the application of wheat straw mulch and lowest (0.393, 0.363, and 0.333 m^3 m^{-3}, respectively) with the rotary hoeing. Further, compared with the control, mulching reduced average soil temperatures by 0.74, 0.66, 0.58 °C at 0.05, 0.15, and 0.30 m, respectively.

Leary *et al.* (2006) conducted the two field experiments at Hawaii to compare the yield of Eggplant in a Buffel grass (*Pennisetum ciliare* L.) mulch system with the yield of Eggplant in a conventional monoculture bare ground system and observed soil moisture levels were higher within the living mulch treatments than in the conventional treatment. Singh *et al.* (2006) reported that mulch treatments retained more soil moisture at all the depths as compared to control and soil temperature was favourably moderated in mulch materials as compared to unmulched treatment in the Brinjal crop.

Moreno and Moreno (2008) experimented the effect of biodegradable and polythene mulches on production of Tomato. Biodegradable films underwent early decomposition, but in general remained functional during use and did not affect yield and fruit quality attributes. The soil temperature remained always higher under polythene mulch than biodegradable films. It also increased soil moisture content than biodegradable film.

Application of plastic as mulch material in horticulture is increasing day by day and play an important role to conserve soil moisture and maintain soil temperature (Panigrahi *et al*., 2008). Organic mulches reduce the maximum soil temperature but raise the minimum soil temperature and significantly reduce soil temperature (Sinkevićiené *et al*., 2009).

In orchards, reduced soil temperatures in summer and minimized diurnal soil temperature variation with mulches was observed by Fourie and Freitag (2010). Singh *et al.* (2010) reported that Paddy straw mulch significantly increased the soil moisture status at various soil depths. Paddy straw mulch followed by Maize straw and grasses had given favourable results with regards to soil moisture.

Kumar and Dey (2011) also reported higher soil moisture content under black polythene mulch and hay mulch materials during entire crop growth period. However, they also reported that black polythene mulch increased the soil temperature.

Mulching at 10 cm thickness, conserved soil water compared to when no mulch was used (Van-Donk *et al.*, 2011). Similarly, the soil temperatures were highest at the shallower soil depths in the unmulched plots. Mulching reduces soil temperature in summer and raises it in winter, which prevents the extremes of temperatures during summer. They also conserve the soil moisture due to reduced evaporation and results in cooling of soil. They further reported that the effect of mulching on the temperature regime of the soil varies according to the capacity of the mulching material to reflect and transmit solar energy. White mulches decreased soil temperature while clear plastic mulches increased soil temperature (Kumar and Lal, 2012).

Shirgure (2012) reported that conservation of soil moisture was found highest, 26.55 % (2000) and 31.84 % (2001) in black polyethylene mulch (100 μ) at 20 cm depth. Amongst the organic mulches grass mulch conserved higher moisture of 25.40 % and 30.16 % during the year 2000 and 2001, respectively in acid lime.

Temperature under mulches was lower than that of the control plots for 32 °C and 34 °C in all the times. The saw dust mulch produced lowest soil temperatures even at stressful temperature at 34 °C especially at 2 pm when the photosynthetic rates are high. By providing lowest temperature for soil when the air temperature is 34 °C helps the higher photosynthesis by the cooling effect to roots at 28.6 °C. Heat loss from the soil is therefore somewhat lower under straw and coir mulching compared with saw dust mulch. This causes soil temperature of a bare soil to be higher than a mulched soil during the day (Godawatte and Silva, 2014).

Kumar *et al.* (2014) studied on effect of various mulches on soil moisture content, soil properties, growth and yield of Kinnow under rainfed condition to assess the response of various mulches (Bajra straw, Maize straw, Ficas leaf, brankad (*Adhotada vassica*), Farm Yard Manure and black polyethylene) on moisture content, soil properties, growth and yield in Kinnow and found that black polyethylene mulch recorded the maximum moisture percentage followed by Farm Yard Manure and brankad. Black polyethylene, Farm Yard Manure and brankad have given favorable results with regards to soil moisture content of the soil. The black polyethylene and Farm Yard Manure were found to be more effective in producing maximum growth extension than rest of the treatments.

Liu *et al*. (2014) conducted an experiment entitled "Straw mulching reduces the harmful effects of extreme hydrological and temperature conditions in citrus orchards" to evaluate whether the straw mulching (SM) practices can help achieve favorable citrus fruit yields. It concluded that the annual total runoff was significantly ($P<0.05$) reduced with straw mulching (SM) as compared to the control (CK). Correspondingly, mean soil water storage in the top 100 cm of the soil profile was increased in the SM as compared to the CK treatment. Results suggested that the small effects on soil water and temperature changes created by surface mulch had limited impact on citrus fruit yield in a normal year. However, SM practices can positively impact citrus fruit yield in extreme weather conditions.

The application of film mulching in six-year old Statuma mandarin (*Citrus unshiu*) increased soil temperature in the 25 cm region, it was about 2 ˚C - 3 ˚C higher than the control (Zhang and Xie, 2014).

Gosh and Bera (2015) found that among the inorganic materials, the black polythene mulch conserved more moisture as compared to white polythene mulch irrespective of month of sampling, in an experiment on effect of mulching on soil moisture, yield and quality of Pomegranate.

Increase in soil moisture content in Eureka Lemon (*Citrus limon* Burm) orchard due to mulching was found significant at both depths of soil (0-15 cm and 15-30 cm). At 50 days after mulching, highest soil moisture content was observed with black polyethylene mulching during both the years of study upto

15 cm depth (9.14 and 10.16 %, respectively). This was followed by the treatment where FYM was applied (8.52 and 9.52 %, respectively) which in turn had higher moisture content than the treatment where Brankad was applied (7.84 and 8.84 %, respectively). The least soil moisture content was recorded in the basins of control plots, which was significantly lower than all other treatments. Similar trend was also observed for the sub-surface soil (15-30 cm) (Kumar *et al*., 2015).

Polythene mulching (without holes) treatment constantly stored soil moisture throughout while other mulches and bare treatment exhibited greater fluctuations (Kader *et al*., 2017).

Hussain *et al.* (2018) observed that mulch with paddy straw mulch followed by glyphosate recorded highest soil moisture content, which was statistically at par with paddy straw mulch and bicolour polythene mulch. Increased soil moisture content below the mulches in various mulches treatments might be due to reduction in soil surface evaporation, increased infiltration percolation capacity of soil and suppression in extreme fluctuation of soil temperature thus retaining the soil moisture in the soil for longer duration.

2.2. Effect of mulching on soil properties

Thakur *et al.* (1997) studied that there was maximum increase in available soil nitrogen in apple *cv.* Red Delicious covered with white clover followed by hay mulching and black polythene mulch. They further observed maximum available phosphorous and soil potassium in hay mulching as compared to other treatments.

Ghuman and Sur (2001) found out that the mulching of the soil surface reduced the bulk density of the soil. Mathews *et al*. (2002) also observed that use of various organic materials as mulches decreased the soil bulk density. 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).

Organic mulch are efficient in reduction of nitrates leaching, improve soil physical properties, prevent erosion, supply organic matter, regulate temperature and water retention, improve nitrogen balance, take part in nutrient cycle as well as increase the biological activity (Hooks and Johnson, 2003; Muhammad *et al.*, 2009; Sarolia and Bhardwaj, 2012).

Verma *et al.* (2005) observed that soil organic carbon and available nitrogen, phosphorous and potassium in Apple *cv*. Red delicious was maximum in grass mulching along with band application of P and K.

Mulching with organic material increases the aggregate stability and structure of soil (Smets *et al*., 2008). 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.

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). Narayan and Lal (2009) reported that in situ mulching with sunhemp coupled with improved tillage in sorghum recorded maximum infiltration rate, pore space, water holding capacity (37.1 cm of 0-30 cm soil layer) and water stable aggregates (48.1 and 49.2 of 0-15 and 15-30 cm soil layer, respectively) and lowest bulk density (1.38 Mg/m^3).

Mulch and tillage significantly affected the soil physical properties and growth of maize as it increased soil moisture contents, organic matter contents, plant height, grain yield and decreased bulk density and soil strength. Soil moisture and organic matter contents were maximum, while soil strength was minimum in deep tillage. Interaction between tillage and mulch levels significantly affect soil physical properties and growth of maize, while non significant for bulk density and plant height. Tillage significantly affected the N and P concentration in maize shoots, while effect on K concentration was non-significant. Mulch significantly increased N and P concentration in maize shoots and its effect on K concentration was non-significant. Interactive effect of mulch and tillage was statistically significant in case of N and P concentration but non-significant in case of K concentration (Pervaiz *et al.*, 2009).

Jordán *et al.* (2010) conducted an experiment on effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain and observed that mulching application significantly improved physical and chemical properties of the studied soil with respect to control, and the intensity of changes was related to mulching rate. The organic matter content was generally increased, although no benefit was found beyond 10 mg ha^{-1} $year^{-1}$. Bulk density, porosity and aggregate stability were also improved with increasing mulching rates, which confirmed the interactions of these properties. Low mulching rates did not have a significant effect on water properties with respect to control, although the available water capacity increased greatly under high mulching rates. Mulching contributed to a reduction in runoff generation and soil losses compared to bare soil, and negligible runoff flow or sediment yield were determined under just 5 mg ha^{-1} $year^{-1}$ mulching rate.

Sharma *et al.* (2010) reported lower bulk density and higher infiltration rate and organic carbon and total nitrogen with sunhemp+leucaena mulch than no mulch in maize-wheat system.

Soil bulk density decreased and soil porosity increased in Kinnow with mowing practice. Mowing also promoted accumulation of soil organic matter and soil aggregation (Hefeez-ur-Rahman *et al*., 2012). Mitra and Mandal (2012) recorded significantly lower bulk density and higher porosity, available N, P and K with rice straw mulch than no mulch in rapeseed-greengram-rice cropping system.

Mulches improved soil aeration and water infiltration rate, lowered the soil bulk density and root penetration resistance than no mulch in spring maize (Javeed *et al.*, 2013). Mixing mulch types with soil caused a quick nitrate release within the first four weeks, which sharply dropped before sixth week while placing mulches on the soil surface resulted to a gradual nitrate release over the study period. Further, soil pH in all mulch treatments decreased within the first four weeks (Kimiti and Gordon, 2013). Cotton stubble mulching in winter canola improved the soil nutrition especially alkaline N and available K as compared to no cotton stubble mulching (Yang *et al.*, 2013).

Wanshnong *et al.* (2013) assessed how different hill slope positions under uniform management practice within a Khasi mandarin orchard (*Citrus reticulata* Blanco) influence biological pools of carbon (C), nitrogen (N), and phosphorus (P), and soil quality. In their study the orchard soils (0 to 15 and 15 to 30 cm depths) of summit, shoulder and backslope hill slopes were analysed during post-monsoon (October–November) and post-winter (March–April). Higher soil moisture content, organic carbon (SOC), pH, size of biological pools {microbial biomass-C, -N and -P; dissolved-OC (DOC), MBC:SOC, potentially mineralizable-N (pMN)}, and soil dehydrogenase and acid-phosphomonoesterase activities were in order of summit > shoulder > > backslope. It revealed that hill slope position and soil moisture had significant influence on variability of soil biological pools. Sizes of biological pools were significantly higher in post-monsoon than post-winter.

Kumar (2014) carried out a study on effect of different organic mulching materials (bajra straw, maize straw, palah leaves (*Butea monosperma*), branker (*Adhatoda vassica*), farmyard manure) on soil properties of aonla (*Emblica officinalis* Gaertn) under rainfed condition of Shiwalik foothills of Himalayas

India. Different organic mulches significantly increased the soil organic carbon and nutrients. Soil properties were highest in FYM and lowest in control. Results showed that effect of type of mulch on soil pH and soil EC was not significant among all the treatments, while on OC (organic carbon), N, P and K was significant in all treatments. Farmyard manure mulch recorded highest soil organic carbon (6.60 and 6.80 g kg^{-1}), soil available nitrogen (238.00 and 239 kg ha^{-1}), soil available phosphorus (20.12 and 21.00 kg ha^{-1}) and soil available potassium (169.92 and 179.48 kg ha^{-1}) in 2009 and 2010 followed by branker. Maize straw mulch with 0-15 cm thickness showed the highest reduction of soil pH and EC in all types of mulch. FYM with 0-15 cm thickness reported the highest percentage of OC, N, P and K. Farmyard manure and branker gave the greatest effect on soil organic carbon and available nutrients.

An experiment was conducted during 2009-2011 to assess the response of various organic and inorganic mulches on moisture content, soil properties, growth and yield in Kinnow. All the organic mulches exhibited significant improvement in soil properties as compared to back polyethylene and control. Amongst the organic mulches, Farm Yard Manure showed better response, followed by brankad, maize straw, bajra straw and ficas leaf. Considerable improvement was also observed in chemical properties of soil after application of mulches. The soil pH and EC of the plant basin showed some reduction in their values, but the difference were non- significant. Organic carbon, available N, available P and available K recorded were highest in Farm Yard Manure closely followed by brankad, maize straw, bajra straw and ficas leaf, while lowest was observed with black polyethylene mulch even lesser than control. It was observed that Farm Yard Manure, brankad, maize straw, bajra straw and Ficas leaf decomposed after rainy season and added lot of humus to the soil (Kumar *et al*., 2014).

The removal of nutrients (N,P,K) from the soil was highest in control plot as the weed from this plot contained maximum amount of N, P and K (4.6

%, 398 mg % and 11.3 %, respectively) and lowest removal of N,P, K was noted from the plants with rice straw and banana leaves mulching (Gosh and Bera, 2015).

In a field experiment in citrus orchard in sloping land, it was recorded that use of straw mulch and grass mulch both lowered soil bulk density values in comparison with control, but in the case of straw mulch there was a significant difference. Soil available P and K was significantly higher in straw mulch treatment than that in control and grass mulch. The use of straw and grass mulch increased soil organic carbon by 15.15 % and 21.14 % respectively (Gu *et al*., 2016).

Alharbi (2017) evaluated on effect of mulch on soil properties under organic farming conditions in center of Saudi Arabia. The obtained result showed that there was slightly decrease in soil pH for mulched treatments compared to unmulched treatment in all soil depths either in the beginning season or end season. The data were non-significant in the beginning season. However, the decreasing in soil pH more pronounced in surface layer compared to subsurface layers. In soil surface layer for mulched treatment, available phosphorus was higher than unmulched treatment by 76.1 and 59.3 % compared to unmulched treatment in the beginning and end season**,** respectively. Finally, under organic farming system, soil moisture and mulch were shown to have a strong indirect influence on the amount of available soil nitrogen, phosphorus and potassium. The highest value of total nitrogen in the soil was recorded in the presence of mulch with the availability of 100 % of the recommended irrigation, where the conditions are very suitable for the mineralization N process. With respect of available phosphorus and potassium, it has given highest values in the presence of mulch with the availability of moisture up to 70 % and 85 % of recommended irrigation.

Wang *et al.* (2017) demonstrated that continuous plastic-film mulch decreased soil pH and the decrease in soil pH was correlated with an increase in soil nitrate concentrations due to the stimulated nitrogen mineralization as a result of rise in soil temperature and moisture under plastic-film mulch.

Lalruantsangi and Hazarika (2018) carried out an investigation to determine the effect of various mulching materials on crop production and soil health in acid lime (*Citrus aurantifolia* Swingle). In their experiment the treatments were T_1- No mulch (Control), T_2- Dry grasses, T_3- Banana leaves, T_4- Paddy straw, T_5- Rice husk, T_6-Wood shavings, T_7- Saw dust, T_8- Polythene mulch with black side facing upward and T_9- Polythene mulch with silver side facing upward. Their study revealed that the maximum organic carbon (3.11 %), available nitrogen (428.47 kg/ha), phosphorus (45.17 kg/ha) and potassium (575.06 kg/ha) content were recorded by saw dust mulch (T_7) and among the organic mulches, saw dust mulch (T_7) proves to have a profound beneficial effect on the soil properties although the other treatments were in par with T_7.

An experiment was conducted to study the effect of mulching on soil properties and post harvest quality of Himsagar mango grown in new alluvial zone of West Bengal at Central Research Farm, Gayeshpur, BCKV in a Randomized Block Design (RBD) with 3 replications during two consecutive years from 2013 to 2015. The results revealed that mulching with different materials on 15 years old mango tree *cv*. Himsagar having uniform growth and vigour, significantly increased the available soil N, P and K, along with increase soil microbial population (Das and Dutta, 2018).

In Kinnow mandarin (*Citrus reticulate cv*. Blanko) field, weed control methods (treatments) such as wood chip mulch, plastic mulch, cultivator, rotavator and glyphosate were applied. Among the treatment, the wood chip mulch showed lower bulk density (1.49 Mg m^{-3}) as compared with the plastic mulch (1.57 Mg m^{-3}) through the soil profile 0-15 cm. The highest bulk density was found in plants where weeds were irradiated with the cultivator (1.72 mg m^{-3}) and the rotavator (1.73 mg m^{-3}) (Sajid *et al*., 2018).

Qu *et al.* (2019) experimented the effect of various mulches on soil physico-chemical properties and tree growth (*Sophora Japonica*) in urban tree pits. A comparison study was conducted to determine the effects of inorganic (cobblestone- CB; water permeable brick- WPB), organic (pine bark- PB; green waste compost- GWC), and living (turf grass- TG) mulches on soil physical and chemical properties at three different depths (0-10 cm, 10-20 cm, and 20-40cm), and on tree growth. Results showed that PB, GWC, and TG improved the soil bulk density, total porosity, macro-porosity, and micro-porosity of the soil to some extent at lower depths, whilst WPB worsened those factors. In addition, by comparing with other treatments, GWC significantly increased the level of all the nutrients. There was no significant difference in the soil properties among the treatments at 20-40 cm.

2.3. Effect of mulching on yield and yield attributes of citrus

Gordon *et al.* (1997) conducted an experiment on "Mulching of avocado orchards to increase yield and fruit size and boost financial rewards a three season summary of research findings" and concluded that mulched trees showed more prolonged and extensive root growth and mulching elevated average fruit yields by 22.6 %, and increased mean fruit mass by 6.6 %. The number of fruit that were considered highly suitable, and acceptable for export, was increased by 45 % and 20 % respectively.

Hassan *et al.* (2000) found maximum TSS, vitamin C and lower acidity vitamin C in Strawberry *cv.* Oso Grand with black polythene mulch. Drip irrigation along with plastic mulch significantly influenced fruit length, breadth as well as weight of Apricot *cv*. New Castle as compare to control (Singh *et al*., 2002).

Shirgure *et al.* (2003) on their study on effect of different mulches on Nagpur mandarin (*Citrus reticulata*) reported that the highest fruit weight (140.5 g) and fruit yield (73.7 kg/tree) was recorded with black polyethylene 100 μ mulch followed by grass mulching (69.7 kg/tree). They also found that total soluble solids (10.20 °B), acidity (0.55 %) and juice content (49.86 %) was the highest with black polyethylene mulch 100 µ.

Gosh and Bauri (2003) recorded higher TSS content in polythene mulch and maximum ascorbic acid content in dry leaf mulching followed by paddy straw mulching when Mango *cv*. Himsagar was grown in rainfed literate soils. They also 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).

Greer and Dole (2003) in their experiment "Aluminum foil, aluminium-painted, plastic and degradable mulches increase yields and decrease insect vector viral diseases of vegetables" concluded that use of plastic mulch can increase crop yield and improve fruit quality and yield are often higher with black plastic compared to bare ground.

Gaikwad *et al*. (2004) observed highest TSS under dry grass mulch in Nagpur mandarin followed by polyethylene mulch while it was least under control. However they found non-significant effect of different mulching treatments on acidity.

Pande *et al*. (2005) reported fruit length and weight of Apple *cv*. Red Delicious was significantly higher with application of dry leaves mulch compared to other mulch treatments. Singh (2005) also reported that in Tomato early flowering, greater number of fruits per plant, larger fruit size and weed control (84.2 %) was observed in black polythene mulch as compared to control.

Agrawal *et al*. (2005) reported that fruit length and width of Mango *cv*. Dashehari was significantly higher under drip irrigation in combination 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 and also recorded 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. Higher titratable acidity of 0.25 % was recorded 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.

The polythene mulched plots produced the highest yield- 94.5 % higher than the unmulched plots, 46.8 % higher than the chemically mulched plots and 25.5 % higher than the plots mulched with rice straw. It was found in a study on effect of mulch on soil temperature, moisture, weed infestation and yield of Groundnut in northern Vietnam (Ramakrishna *et al*., 2006).

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.

Ali and Gaur (2007) recorded that number of flower per plant was maximum in Strawberry with black polythene mulch (17.87) which was statistically at par with paddy straw (17.12) and sugar-cane trash (16.87). They also observed that, after transplanting strawberry plants number of days taken to flowering was less in black polythene (53) as compared to paddy straw (55.12) and control (58.18). Further, they reported maximum fruit retention under black polythene (13.75 %) while minimum in control (11.50 %).

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.

Panigrahi *et al*. (2008) studied on the effect of drip irrigation and plastic mulch on the performance of Nagpur mandarin grown in central India which showed that the highest magnitude of growth parameters was recorded in drip irrigation regimes with plastic mulch with 35.7 % water saving.

Abouziena *et al*. (2008) conducted an experiment on "Comparison of weed suppression and mandarin fruit yield and quality obtained with organic mulches, synthetic mulches, cultivation, and glyphosate" and concluded that plastic mulches of 200 µm and 150 µm, cattail (*Cyprus articulatus* L.) mulch (two or three layers) and two mulch layers of rice (*Oryza sativa* L.) straw treatments significantly increased the fruit yield per tree by 24 %, 18 %, 20 %, 11 %, and 12 % more than cultivation treatment, respectively, without significant differences among these superior treatments.

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.

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.

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. They also 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 fruit.

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) also recorded 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) 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. Maximum TSS of 12.16 % was recorded with black polyethylene in combination with gramaxone (1 litre/ha). They also reported that TSS under paddy straw and sarkanda was higher as compared to control and the highest titratable acidity was under control whereas least was observed under paddy straw mulch.

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. They recorded significantly higher TSS under transparent polyethylene mulch followed by black polyethylene and also reported higher TSS under organic mulches then control. Significantly higher fruit acidity in Strawberry was observed under transparent polyethylene followed by black polyethylene. The minimum fruit acidity was obtained under control.

The fruit weight, TSS, acidity and juice content of acid lime was higher with black polythene was maximum with black polythene mulch 100 micron and grass mulch (Shirgure, 2012). 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 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. The highest TSS of 7.63 ºB was recorded under black polythene mulch whereas, it was found lower in control (6.67 ºB). Highest acidity of 0.80 % under control and least acidity of 0.64 % was found under black polythene mulch.

Sandhu and Bal (2014) reported that by use of irrigation at 20 % ASMD (available soil moisture depletion) and mulching with black polythene sheet in Lemon (*Citrus limon* (L.) Burm.) *cv*. Baramasi, the maximum fruit size (fruit length and fruit breadth) was recorded (5.69 cm and 5.30 cm during 2008 and 5.86 cm and 5.46 cm during 2009). Likewise, the fruit weight was found to exhibit maximum value (71.33 g and 72.40 g) during both the years of experiment *i.e*. 2009 and 2010.

Kumar *et al.* (2014) studied on effect of various mulches on soil moisture content, soil properties, growth and yield of Kinnow under rainfed condition, to assess the response of various mulches [bajra straw, maize straw, ficas leaf, brankad (*Adhotada vassica*), Farm Yard Manure and black polyethylene] on moisture content, soil properties, growth and yield in Kinnow and recorded that plant treated with black polyethylene mulch recorded highest yield (3.62) followed by Farm Yard Manure (3.45) and brankad (3.36). Fruit yield/plant and fruit size were highest with black polyethylene mulch, followed by Farm Yard Manure and brankad. Among the organic mulches evaluated, brankad better responses are low cost, easily available local areas followed by bajra straw, maize straw and grasses. They also reported that total soluble solids were highest with black polyethylene mulch, followed by Farm Yard Manure and brankad.

Zhang and Xie (2014) investigated on effects of plastic film mulching on quality and appearance of Statuma mandarin fruit and observed that mulching during the cell division and early mature stages increased total sugar and reduced sugar content of fruit as well as the Vitamin C content, compared to the control. Film mulching during the cell division phase resulted in higher edible fruit rate. Mulching during the early mature period effectively enhanced the content of total and reduced sugar and Vitamin C and decreased the titratable acid content.

In an experiment on effect of different mulching materials on Eureka Lemon (*Citrus limon* Burm) it was found that plots treated with black polyethylene mulch recorded highest yield (1848 kg/ha) followed by farmyard manure (1780 kg/ha) and brankad (1744 kg/ha) (Kumar *et al*., 2015).

Manoj *et al.* (2015) reported that, maximum fruit length (7.16 cm), breadth (7.28 cm), fruit weight (177.41 g), maximum number of fruits (246.72 fruits/plant) and highest yield (43.77 kg/plant) was recorded with black polythene 200 µ mulch in Kinnow whereas lowest yield (32.16 kg/plant) was recorded in control.

Pandey *et al*. (2015) observed that in strawberry black polythene mulch performed better than other mulches tested in terms of yield parameters (fruit weight, no of fruits/plant fruit size and yield/plant).

Das *et al*. (2016) did a research to study the effect of mulching on yield, physico-chemical qualities and leaf mineral composition of litchi grown in new alluvial zone of West Bengal, it was carried out over three years in the farmer's field of Litchi *cv*. Bombai. Among different mulches, paddy straw mulch showed maximum (22.80 %) soil moisture content and fruit retention (18.42 no's panicle^{-1}) with highest (94.42 kg plant^{-1}) yield followed by mulches with mango leaves. This treatment also showed maximum TSS (20.20 °Brix), total sugar (14.80 %) with minimum (0.60 %) acidity of fruit.

Studies were carried out in NA-7 cultivar of Aonla (*Emblica officinalis* Gaertn) to assess the efficacy of organic and inorganic mulching materials on growth, flowering and yield during 2013 and 2014. Treatments consisted of mulching materials, *viz.*, black polythene, white polythene, paddy straw, saw dust, sarkanda, dry grass with control (unmulched). Black polythene mulch was superior to all other mulching treatments in terms of yield attributes as it registered maximum fruit set (56.15 %), minimum fruit drop (55.87 %) and higher yield/tree (72.77 kg/tree) and thus it was concluded that black polythene improved the tree growth, flowering, fruit production and lowered weed population of Aonla *cv.* NA-7 as compared to control in rainfed areas (Iqbal *et al.*, 2016).

Kinnow fruit plants raised with Sal leaves mulch produced 4.94 and 16.02 per cent more fruits than lantana leaves mulch and control respectively, besides improving the microclimate. The treatments of organic mulches improved the fruit quality of the fruit over control whereas Sal leaves treatment was found superior than Lantana leaves treatment in improving the fruit quality in terms of fruit size, fruit weight, total sugar, total soluble solids and acidity (Rathore *et al.*, 2016)

Lalruatsangi and Hazarika (2018) studied the effects of various mulching materials on Acid Lime during 2014-2015. They found that treatments had a significant influence on yield and yield attributing parameters where polythene mulch recorded the highest number of fruits per plant (163.0), fruit weight (50.22 g) and fruit yield per plant (7.81 kg) while dry grasses mulch recorded highest number of fruits per branch (7.50) and fruit retention (44.71 %). With respect to quality parameters of fruit, polythene mulch recorded highest total sugar (0.40 %) and reducing sugar (0.61 %) while significant increase on titratable acidity (6.93 %) and ascorbic acid content (33.46 mg/100g) was observed in dry grass mulch.

The influence of different mulches on yield and fruit quality parameters of Mango *cv*. Himsagar such as fruit weight, fruit length and diameter, yield and bio-chemical composition of fruit was found with application of black polythene mulch followed by paddy husk and paddy straw. Among the different mulches black polythene mulch showed maximum fruit weight (263.42 g), fruit length/diameter (8.72/7.92 cm), and yield (271.41 no./tree) followed by paddy husk in relation to fruit weight (250.11 g), fruit length/ diameter (8.41/7.66 cm) and yield (243.72 no./tree) while unmulched (control) gave the minimum values (Das and Dutta, 2018).

Sakariya *et al*. (2018) conducted an experiment on performance of plastic mulch on Papaya crop for two varieties Madhubindu and Taiwan. Papaya was grown under mulch (silver black plastic mulch and black plastic mulch) and no mulch condition in JAU, Junagadh (Gujarat). The maximum number of flowers (9.60), number of fruits (10.30) was observed in silver black plastic mulch and all these parameters were found minimum under no mulch condition.

Weed control methods (treatments) wood chip mulch, plastic mulch, cultivator, rotavator and glyphosate, were applied on Kinnow mandarin (*Citrus reticulate cv*. Blanko) field. Among the mulches, the wood chip mulch gave higher yield (11.88 ton ha^{-1}) as compared to the plastic mulch (10.58 ton ha^{-1}). The lowest yield was found in plants where weeds were irradiated with the cultivator (3.81 ton ha^{-1}) and the rotavator (4.71 ton ha^{-1}) (Sajid *et al*., 2018).

2.4. Economics of mulching materials

Sutagundi (2000) reported that treatment receiving straw mulch recorded significantly higher net returns (Rs. 30,894 ha^{-1}) and benefit: cost ratio (1.80:1) compared to control as result of soil water conservation in Chilli.

Verma *et al*. (2008) reported higher yield and B:C ratio with dust mulching than straw and no mulching in Summer Moong. Oak leaves used as bio-mulch in organic ginger increased yield by 43 % and net returns by 61 % as compared to no mulching (Singh *et al*., 2014).

Kumar *et al.* (2014) calculated the cost of various mulch materials in a Kinnow mandarin field. The price of mulch material for each tree per treatment was calculated separately and time of its application was converted into man days at the rate of Rs. 110/- per day (8 hours). The highest net income of Rs. 98.80 tree^{-1} was obtained from the organic mulch which gave an additional income of Rs 11.80 tree^{-1} as compared to control. The poor aeration, non decomposable nature and high cost are the constraints of using black polyethylene as mulch material. Among the organic mulches evaluated, brankad better responses are low cost, easily available local areas followed by Bajra straw, Maize straw and grasses.

Gosh and Bera (2015) reported that the highest net income of Rs 383.50 plant^{-1} was obtained from saw dust mulched plant and calculated the net profit as Rs 139.50 over the control plant (unmulched). The second profitable treatment was white polythene mulch followed by Rice straw (chopped) and Rice straw mulches which gave an extra income of Rs 62.50 and Rs 51.00 plant^{-1}, respectively over control.

A field experiment entitled “Effect of mulching on economics studies of vegetables as intercrop in the Kinnow orchard under agro-climatic condition of Bastar plateau of Chhattisgarh” was conducted during the *Rabi* season of 2016-17 at the Instructional farm, College of Horticulture and Research Station, Jagdalpur. The treatment consisted of mulched and non-mulched plots in four different crops *viz.*, Tomato, Chilli, Brinjal and Bitter Gourd. The mulched plots of Tomato recorded the maximum yield ha^{-1} (130.33 q) and benefit cost: ratio of (2.66). However, the non-mulched plots recorded the maximum yield ha^{-1} (100.00 q) and benefit cost: ratio of 2.56 (Kumar *et. al.*, 2018).

Hussain *et al.* (2018) investigated maximum benefit: cost ratio (5.00:1 and 5.05:1) was recorded with paddy straw mulch followed by glyphosate, whereas the minimum benefit: cost ratio was recorded under atrazine followed by pendimethalin. Paddy straw mulch, Cowpea and bicolour polythene mulch recorded satisfactory benefit: cost ratio. The increase in benefit: cost ratio may be due to higher yield of good quality fruits under these treatments.

CHAPTER III

MATERIALS AND METHODS

MATERIALS AND METHODS

The present investigation entitled, "Effect of mulching on soil water conservation and performance of Khasi mandarin (*Citrus reticulata* Blanco) in mid-hill regions of Mokokchung District of Nagaland" was carried out in the farmer's field of Chuchuyimlang Village of Mokokchung District of Nagaland, during the year 2016 to 2018. The specifics of the experimental site, materials used and methodology applied during the course of study are deliberated in this chapter.

3.1. General information

3.1.1. Experimental site

The present investigation will be carried out in Chuchuyimlang Village under Mokokchung District of Nagaland. The geo-coordinates of the selected village are 26°20'77" N latitude and 94°29'76" E longitude, at an elevation of 1325 metres above mean sea level (msl). The analysis of the harvested fruits and soil parameters were done in the Laboratory of Department of Soil and Water Conservation, SASRD, Medziphema Campus, Nagaland University, Medziphema under Dimapur District, situated in the foot hills of Nagaland at an altitude of 305 meters above mean sea level.

3.1.2. Climatic condition

The climate of the experimental site is sub-tropical humid type, moderate temperature and receives medium to high rainfall. The temperature ranges between 4.5˚C-18.4˚C during winter and 25˚C to 29.3˚C during summer. The dry period occur from November to March. The average rainfall ranges between 1600 mm to above 2500 mm.

3.1.3. Soil condition

The pH of the soil was 4.8 and the organic carbon content was 2.43 %. The available N, P and K were 310.72, 8.39 and 159.56 kg ha^{-1} respectively.

Plate 1: General view of the experimental farm

Table 1: Meteorological data recorded during the period of investigation (February 2016 to February 2017 and February 2017 to February 2018) at Mokokchung, Nagaland.

Month	2016-2017				2017-2018			
	Temperature (°C)		Mean Relative Humidity (%)	Rainfall (mm)	Temperature (°C)		Mean Relative Humidity (%)	Rainfall (mm)
	Max.	Min.			Max.	Min.		
February	19.1	11.6	67.4	4.2	17.4	8.5	64.0	6.3
March	21.9	15.3	60.0	8.0	17.8	10.9	69.0	10.1
April	24.4	17.1	69.9	16.7	18.1	13.2	80.0	8.8
May	25.4	17.5	71.0	11.2	19.0	14.4	76.0	7.6
June	26.1	19.9	82.0	11.5	23.5	15.9	80.0	10.3
July	26.1	19.6	87.0	15.5	25.6	18.5	68.0	9.7
August	27.4	20.7	83.0	15.5	26.9	21.1	78.0	6.3
September	26.0	19.9	84.0	11.7	26.4	21.4	80.2	7.7
October	25.7	19.4	83.0	4.0	25.4	18.8	79.0	11.9
November	18.7	14.2	79.0	13.3	23.4	17.2	78.0	7.5
December	15.6	10.3	73.8	8.4	19.5	13.7	75.8	11.1
January	13.2	6.5	67.3	9.0	15.3	9.6	76.0	28.2
February	17.4	8.5	64.0	6.3	15.5	7.5	46.0	0.5

Source: DSCO, Meteorological observatory, Mokokchung

The bulk density and particle density was 1.37 and 2.32 g cm^{-3}, respectively. The water holding capacity was 27.05% and percent aggregates >0.25mm was 61.92.

3.2. Experimental details

3.2.1. Source of materials

Khasi Mandarin trees of 15-years old were selected for fruit collection at Chuchuyimlang Village under Mokokchung district of Nagaland.

3.2.2. Experimental design:

The experiment was carried out in Completely Randomized Design (CRD).

Number of treatments	: 9 (Nine)
Number of replications	: 3 (Three)
No. of trees per treatment	: 4
No. of trees per replication	: 4x9 = 36
Total No. of trees	: 36x3= 108

3.2.3. Treatments details:

Mulching materials :

M_0- No mulch

M_1- Rice husk

M_2- Saw dust

M_3- Chopped banana leaves & pseudo stem

M_4- FYM

M_5- Forest leaves

M_6-Rice straw

M_7-Transparent polythene (100μ)

M_8-Black polythene (100μ)

Plate 2a: Application of fertilizers

Plate 2b: Recording of soil temperature at different depth

Plate 2c: Moisture conservation after the application of transparent polythene

Plate 3: Application of different mulching materials

For treatment M_1, M_2, M_3, M_4, M_5 & M_6, 5cm layer of rice husk, saw dust, chopped banana leaves and pseudo-stem, FYM, forest leaves & rice straw were applied above the soil surface around the tree trunk up to a distance of one metre radius, respectively. On an average the requirement of rice husk, saw dust, chopped banana leaves & pseudostem, FYM, forest leaves, rice straw, and transparent polythene & black polythene was 6.0 kg, 4.0 kg, 10.0 kg, 8.0 kg, 4.5 kg, 5.0 kg and 3.5 m^2 per plant.

The recommended dose of fertilizer (RDF) for the investigation was 900 g N, 700 g P_2O_5, 600 g K_2O per plant. The Citrus trees were maintained pest and disease free throughout the experiment.

3.3. Experimental methods

3.3.1. Moisture content & soil temperature

Moisture content of soil and soil temperature from individual plots were measured at 0-30 cm and 30-60 cm depth and at 3-weeks interval till the harvest of the fruits. The soil moisture was measured by Gravimetric method (Black, 1965). The soil sample that was weighed was kept in the oven at 105 ºC and dried to constant weight. The difference in weight is considered to be water present in the sample of the soil. The soil temperature was recorded with the help of soil thermometer.

3.3.2. Nutrient status of the soil after harvest

3.3.2.1. Bulk density

The initial soil samples and the soil samples collected from individual plots after harvest of citrus were analysed for the following properties. The bulk density of the soil was determined by the core method as described by Baruah and Barthakur (1997).

3.3.2.2. Particle density

The particle density of the soil was determined by the Pycnometer method.

3.3.2.3. Maximum water holding capacity

In determination of maximum water holding capacity (WHC), oil sample were filled in Keen Rackzowaski boxes and tapped uniformly and was saturated overnight. After the saturation, the samples were weighed and placed in oven for continuous 48 hours at equilibrium temperature of 105 ˚C. The samples were allowed to cooled and then weighed. Lastly, the maximum water holding capacity (WHC) was calculated by the difference of weight expressed in percentage (Piper, 1966).

3.3.2.4. Per cent aggregates > 0.25 mm

For the determination of per cent aggregates >0.25mm air-dried natural clod samples were broken into gentle pressure and passed through 8 mm mesh sieve and retained on 5 mm sieve. Fifty grams of soil retained on 5 mm mesh sieve were transferred on the sieve of the nest of the sieves arranged in the order of 5 mm, 2 mm, 1 mm, 0.5 mm and 0.25 mm. The sieve was then emerged under water for 30 minutes in Yoder's apparatus for 30 minutes. Fractions retained in each sieve was collected, oven dried at equilibrium temperature for 24 hours, weighed and per cent aggregates was calculated in percentage.

3.3.2.5. Soil pH

The determination of soil pH was done in 1:2.5 soil water suspension by using glass electrode pH meter.

3.3.2.6. Organic carbon content

Organic carbon was analyzed by the Wet Digestion Method of Walkley and Black as detailed by Jackson (1973). The result was expressed in terms of %.

3.3.2.7. Available Nitrogen (N)

The available N content of the soil was determined by the Alkaline-Potassium Permanganate method of Subbiah and Asija (1956). The result was expressed in kg ha^{-1}.

3.3.2.8. Available Phosphorus (P)

The available P in soil was extracted by Bray's method No.1 (Brays and Kurtz, 1945). The P content in the soil was estimated colorimetrically (Dickman and Bray, 1940). The result was expressed in kg ha^{-1}.

3.3.2.9. Available Potassium (K)

The available K was extracted from the soil with neutral normal ammonium acetate (Jackson, 1973) and estimated flame photometrically. The result was expressed in kg ha^{-1}.

3.3.3. Growth and yield attributes of the fruit

3.3.3.1. Yield attributes

3.3.3.1.1. Days to flowering

The days were counted from the day of treatment given till the emergence of first flower.

3.3.3.1.2. Fruit size

The average length of the fruit was measured from distal end to the apical tip of fruit and for the breadth, it was measured at the wider portion of the fruit with the help of Vernier Calliper. The result was expressed in centimeter (cm).

3.3.3.1.3. Fruit weight

The weight of the fruit was measured with the electronic weighing balance and the result expressed in grams (g).

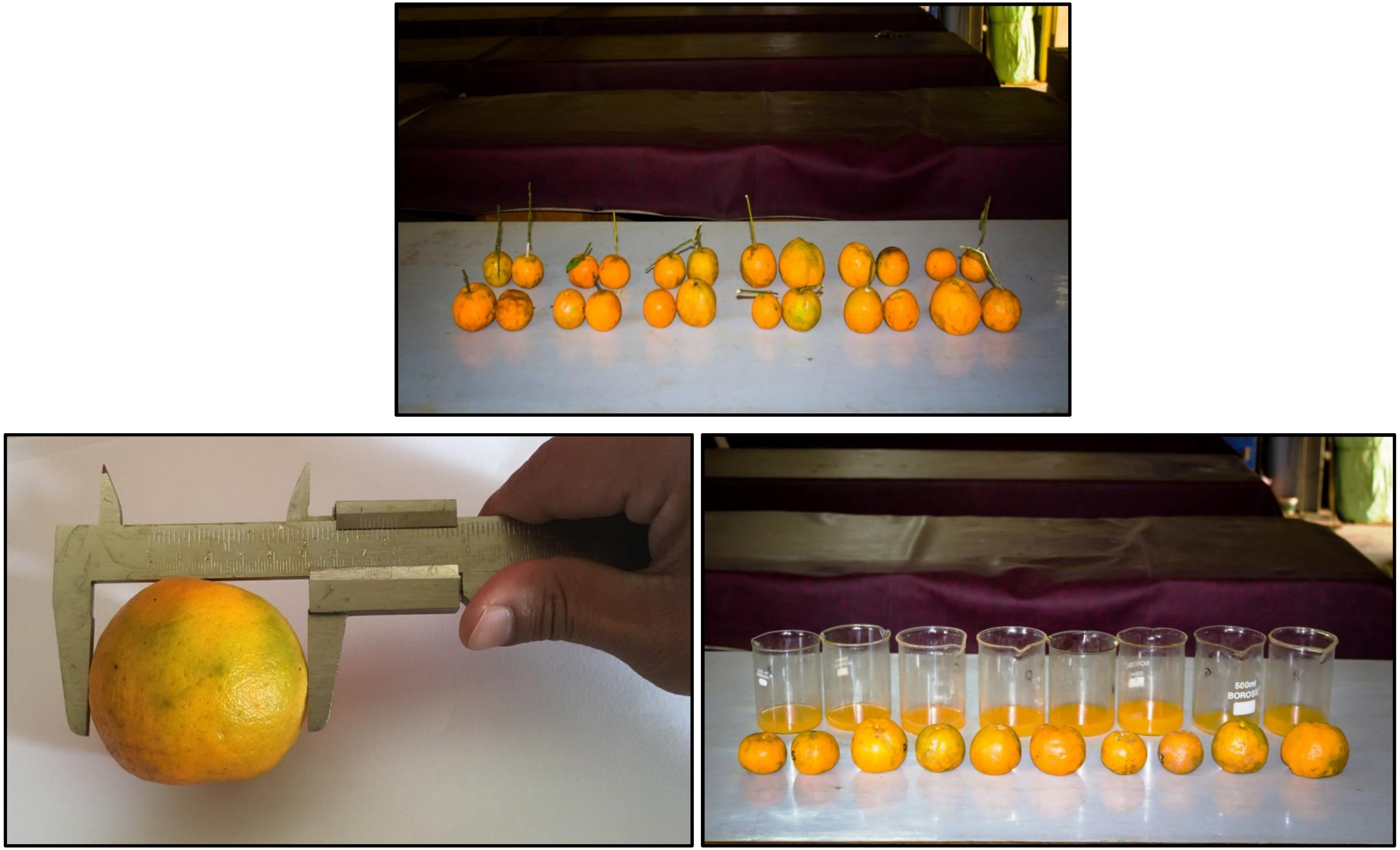

Plate 4: Laboratory analysis of the fruit quality at SASRD, Medziphema

3.3.3.1.4. Fruit yield/tree (kg)

The yield per tree in kilogram is calculated as the product of average fruit weight and the number of trees per plant.

3.3.3.1.5. Projected yield (q/ha)

The projected yield is calculated as the product of average yield per tree and the number of trees per hectare and is expressed in quintals per hectare.

3.3.3.2. Quality attributes

3.3.3.2.1. Total soluble solids (^{0}Brix)

The Total soluble solids (TSS) content of the juice was determined with the help of ERMA Hand Refractometer, calibrated at 20 $^{\circ}$C temperature, and the results were represented as ^{o}Brix.

3.3.3.2.2. Titratable Acidity

Total acidity was determined by titrating the juice against standard alkali solution (0.1 N NaOH) using phenolphthalein as the indicator according to the method described in A.O.A.C. (1984), and expressed as percentage of citric acid in the fruit juice.

3.3.3.2.3. Colour

The colour of the fruit was measured by the visual rating method using the scale mentioned below-

Grade of the fruit	Rating scale
Very good	5
Good	4
Fair	3
Poor	2
Very poor	1

3.3.3.2.4. Firmness

Parameter of firmness of the fruits was estimated by five different panels. This method was laid out using a five level Hedonic Scale developed by Amerine *et al.* (1965). The test was done at SASRD NU Medziphema. The level of firmness was rated at five different levels as mentioned below;

1- Very hard, 2- Hard, 3- Moderately hard, 4- Soft and 5- Very soft.

3.3.3.2.5. Reducing Sugar

Reducing sugar of fruit was determined by titrating the fruit juice against Fehling A and Fehling B reagents by using Methylene blue as an indicator following the method of Lane and Enyon (Ranganna, 2008). Precipitation of deep brick colour of the solution indicated the end point. The results obtained were presented in terms of percentage of fruit juice.

3.3.4. BCR (Benefit Cost Ratio)

BCR was calculated taking into consideration all the cost incurred for the fruits such as labour charges, cost of irrigation, cost of harvesting, cost of fertilizers and transportation cost on the basis of yield of fruits per treatment.

3.3.5. Statistical analysis

The data obtained during the experiment was analyzed statistically by applying one-way analysis of variance (ANOVA) as described by Gomez and Gomez (1984). Further, differences between treatments were analysis of variance at a significance level of 0.05 and after conducting the F-test, the homogeneity of variances between the different treatments was tested by applying Duncan Multiple Range Test (DMRT) test to find out the significant differences between mean values.

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

4.1. Moisture content & soil temperature

4.1.1. Soil moisture

The established data (Table 2 & 3) on the soil moisture percentage at 0-30 cm of the soil showed that, the highest soil moisture content in both the experimental year was recorded in black polythene (M_8) mulch. The moisture percentage was 30.28 and 31.52 %, respectively and the lowest soil moisture content percentage was recorded in no mulch (M_0) with 21.32 and 22.12 %, respectively *i.e.* during the initial reading. The amount of soil moisture content percentage during the consecutive readings increased in all the treatments however, during the first experimental year decline in the moisture content percentage was observed during the final stage. Whereas, in the second year of experiment the soil moisture percentage increased insignificantly in all the readings. The difference in the moisture percentage of soil could be due to different monthly rainfall pattern in both the seasons.

The soil moisture percentage at 30-60 cm of the soil confirmed that the lower soil profile revealed higher soil moisture content. The highest soil moisture percentage during 2016 and 2017 was recorded in black polythene (M_8) mulch with moisture content of 30.98 and 32.05 % respectively and the lowest was found in no mulch (M_0) with a moisture content of 21.42 and 22.12 % respectively, in the initial reading. Similar trend was recorded during the succeeding readings with some fluctuations with insignificant increase and decrease in the soil moisture content.

From the results given in Table 2, 3, 4 & 5, it is observed that black and transparent polythene mulching was significantly superior in moisture retention which was followed by transparent polythene (M_7) and FYM (M_4) and the least was recorded in no mulch (M_0). It could be concluded that rice husk (M_1), saw dust (M_2), chopped banana leaves & pseudo-stem (M_3), resulted in significant

Table 2: Effect of different mulching materials on soil moisture percentage at 0-30 cm of Khasi mandarin

Treatments	*Soil moisture percentage at 0-30 cm (%)*											
	1st reading			*2nd reading*			*3rd reading*			*4th reading*		
	2016	*2017*	*Pooled*	*2016*	*2017*	*Pooled*	*2016*	*2017*	*Pooled*	*2016*	*2017*	*Pooled*
M_0: No mulch	21.32^{i}	22.12^{g}	21.72^{i}	21.48^{h}	22.26^{g}	21.87^{g}	22.20^{h}	22.57^{h}	22.38^{i}	22.32^{g}	22.86^{h}	22.59^{h}
M_1: Rice husk	25.28^{h}	26.14^{f}	25.71^{h}	25.65^{g}	26.47^{f}	26.06^{f}	25.78^{g}	26.75^{g}	26.27^{h}	26.10^{f}	27.15^{g}	26.63^{g}
M_2: Saw dust	26.57^{f}	27.46^{e}	27.02^{f}	26.62^{f}	27.50^{e}	27.06^{e}	27.15^{e}	28.36^{e}	27.76^{f}	27.47^{e}	29.07^{e}	28.27^{e}
M_3: Chopped banana leaves & pseudostem	25.92^{g}	26.70^{f}	26.31^{g}	26.43^{f}	27.15^{ef}	26.79^{e}	26.62^{f}	27.28^{f}	26.95g	27.02^{e}	28.26^{f}	27.64^{f}
M_4: FYM	28.96^{c}	29.82^{c}	29.39^{c}	29.47^{c}	30.36^{c}	29.92^{c}	29.22^{c}	30.52^{c}	29.87^{c}	29.90^{c}	30.70^{c}	30.30^{c}
M_5: Forest leaves	28.12^{d}	28.98^{d}	28.55^{d}	28.90^{d}	29.25^{d}	29.07^{d}	28.96^{c}	30.15^{c}	29.56^{d}	29.88^{c}	30.38^{cd}	30.13^{c}
M_6: Rice straw	27.53^{e}	28.54^{d}	28.04^{e}	28.26^{e}	29.12^{d}	28.69^{d}	28.54^{d}	29.54^{d}	29.04^{e}	28.17^{d}	29.77^{de}	28.97^{d}
M_7: Transparent polythene (100μ)	29.65^{b}	30.72^{b}	30.18^{b}	31.60^{b}	32.63^{b}	32.12^{b}	32.45^{b}	33.20^{b}	32.83^{b}	33.00^{b}	34.18^{b}	33.59^{b}
M_8: Black polythene (100μ)	30.28^{a}	31.53^{a}	30.91^{a}	32.40^{a}	33.40^{a}	32.90^{a}	33.07^{a}	34.42^{a}	33.74^{a}	33.87^{a}	35.30^{a}	34.59^{a}
SEm±	*0.16*	*0.21*	*0.13*	*0.21*	*0.24*	*0.16*	*0.10*	*0.12*	*0.08*	*0.18*	*0.24*	*0.15*
CD (p=0.05)	*0.48*	*0.62*	*0.38*	*0.62*	*0.73*	*0.46*	*0.29*	*0.37*	*0.23*	*0.53*	*0.71*	*0.43*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance.

Means within columns were separated by Duncan's multiple range test (DMRT).

1st reading is taken from the first week of October and the subsequent readings were taken at an interval of 21 days till the final harvest.

Table 3: Effect of different mulching materials on soil moisture percentage at 0-30 cm of Khasi mandarin

Treatments	*Soil moisture percentage at 0-30 cm (%)*								
	5th reading			*6th reading*			*7th reading*		
	2016	*2017*	*Pooled*	*2016*	*2017*	*Pooled*	*2016*	*2017*	*Pooled*
M_0: No mulch	22.62^{i}	22.88^{h}	22.75^{i}	22.52^{g}	23.10^{g}	22.81^{i}	22.40^{h}	23.65^{h}	23.03^{h}
M_1: Rice husk	26.45^{h}	27.25^{g}	26.85^{h}	26.28^{f}	27.26^{f}	26.77^{h}	26.27^{g}	27.34^{g}	26.80^{g}
M_2: Saw dust	27.72^{f}	29.16^{e}	28.44^{f}	27.50^{e}	30.10^{d}	28.80^{f}	27.62^{f}	30.20^{e}	28.91^{e}
M_3: Chopped banana leaves & pseudostem	27.38^{g}	28.65^{f}	28.02^{g}	27.37^{e}	28.74^{e}	28.06^{g}	27.26^{f}	28.82^{f}	28.04^{f}
M_4: FYM	30.16^{c}	30.88^{c}	30.52^{c}	29.88^{c}	31.05^{c}	30.47^{c}	29.82^{c}	31.17^{c}	30.50^{c}
M_5: Forest leaves	29.60^{d}	30.50^{c}	30.05^{d}	29.50^{c}	30.65^{cd}	30.07^{d}	29.34^{d}	30.96^{cd}	30.15^{c}
M_6: Rice straw	29.15^{e}	29.98^{d}	29.57^{e}	28.82^{d}	30.14^{d}	29.48^{e}	28.85^{e}	30.52^{de}	29.69^{d}
M_7: Transparent polythene (100μ)	33.60^{b}	34.52^{b}	34.06^{b}	33.20^{b}	34.78^{b}	33.99^{b}	33.30^{b}	34.80^{b}	34.05^{b}
M_8: Black polythene (100μ)	34.12^{a}	35.40^{a}	34.76^{a}	33.92^{a}	35.52^{a}	34.72^{a}	33.86^{a}	35.62^{a}	34.74^{a}
SEm±	*0.11*	*0.16*	*0.10*	*0.15*	*0.20*	*0.13*	*0.14*	*0.20*	*0.12*
CD (p=0.05)	*0.33*	*0.48*	*0.28*	*0.44*	*0.60*	*0.36*	*0.42*	*0.59*	*0.35*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance. Means within columns were separated by Duncan's multiple range test (DMRT).

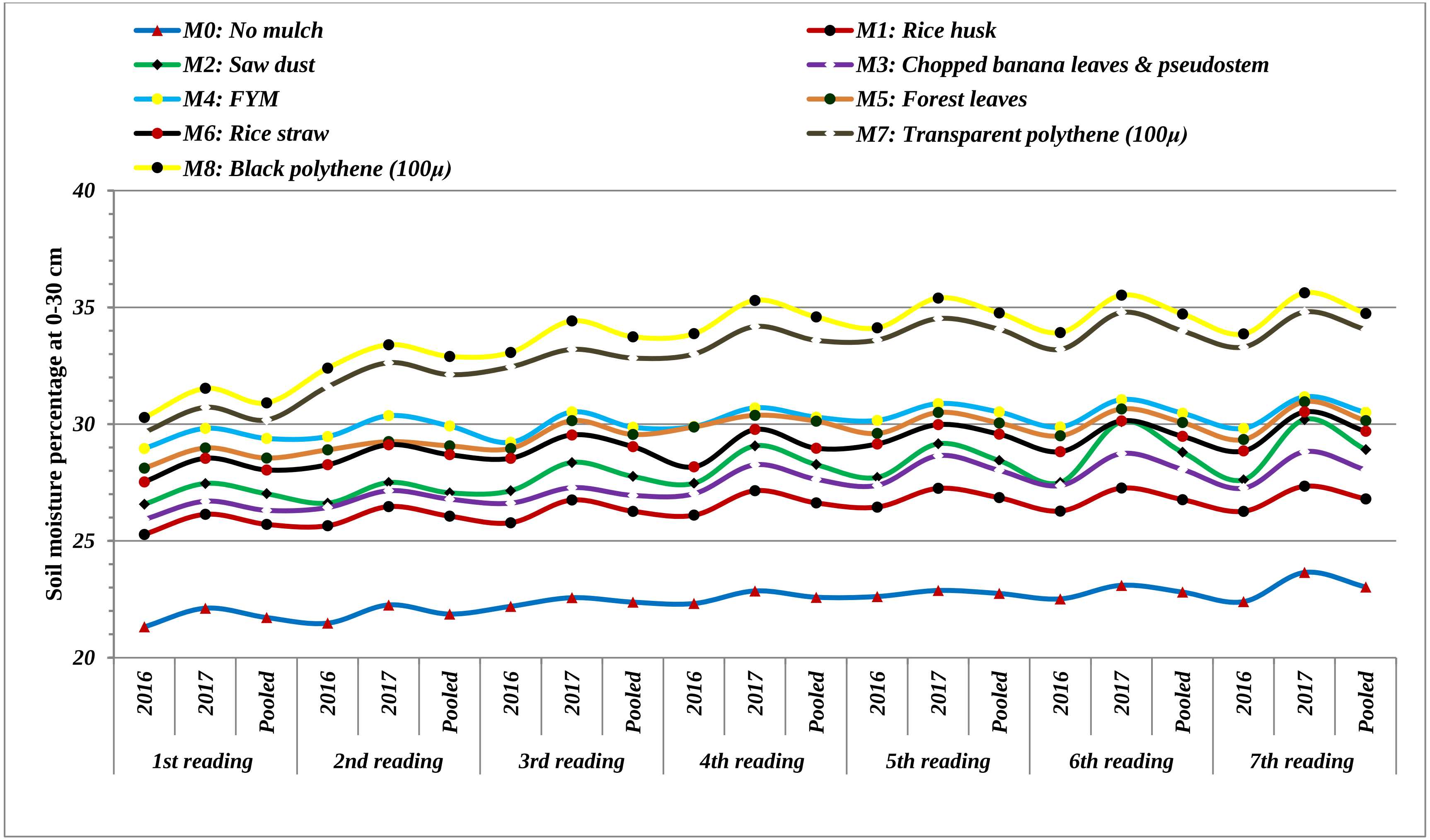

Fig 1: Effect of different mulching materials on soil moisture percentage at 0-30 cm of Khasi mandarin

Table 4: Effect of different mulching materials on soil moisture percentage at 30-60 cm of Khasi mandarin

Treatments	***Soil moisture percentage at 30-60 cm (%)***											
	1st reading			***2nd reading***			***3rd reading***			***4th reading***		
	2016	***2017***	***Pooled***	***2016***	***2017***	***Pooled***	***2016***	***2017***	***Pooled***	***2016***	***2017***	***Pooled***
M_0: No mulch	21.42^{f}	22.45^{e}	21.94^{g}	22.12^{i}	22.70^{h}	22.41^{i}	22.45^{g}	23.20^{g}	22.83^{i}	23.00^{h}	23.32^{g}	23.16^{h}
M_1: Rice husk	25.48^{e}	26.50^{d}	25.99^{f}	25.77^{h}	26.77^{g}	26.27^{h}	25.92^{f}	27.12^{f}	26.52^{h}	26.28^{g}	27.48^{f}	26.88^{g}
M_2: Saw dust	26.62^{d}	27.74^{c}	27.18^{e}	27.07^{f}	28.40^{f}	27.73^{f}	27.30^{e}	28.62^{e}	27.96^{f}	27.62^{f}	28.37^{e}	28.00^{f}
M_3: Chopped banana leaves & pseudostem	26.30^{d}	27.10^{cd}	26.70^{e}	26.70^{g}	27.92^{f}	27.31^{g}	26.94^{e}	28.00^{e}	27.47^{g}	27.28^{f}	28.98^{e}	28.13^{f}
M_4: FYM	29.19^{b}	29.88^{b}	29.54^{c}	29.72^{c}	30.75^{c}	30.23^{c}	30.38^{c}	31.16^{c}	30.77^{c}	31.16^{c}	31.86^{c}	31.51^{c}
M_5: Forest leaves	28.48^{bc}	29.55^{b}	29.02^{c}	29.05^{d}	30.47^{d}	29.76^{d}	29.30^{d}	30.92^{c}	30.11^{d}	30.08^{d}	31.15^{d}	30.61^{d}
M_6: Rice straw	27.90^{c}	28.86^{b}	28.38^{d}	28.65^{e}	29.72^{e}	29.19^{e}	29.00^{d}	30.18^{d}	29.59^{e}	29.44^{e}	30.60^{d}	30.02^{e}
M_7: Transparent polythene (100μ)	30.25^{a}	31.52^{a}	30.88^{b}	32.52^{b}	33.60^{b}	33.06^{b}	32.74^{b}	34.24^{b}	33.49^{b}	33.92^{b}	35.00^{b}	34.46^{b}
M_8: Black polythene (100μ)	30.98^{a}	32.05^{a}	31.52^{a}	33.05^{a}	34.46^{a}	33.75^{a}	33.95^{a}	35.20^{a}	34.58^{a}	34.68^{a}	35.97^{a}	35.32^{a}
SEm±	*0.26*	*0.33*	*0.21*	*0.12*	*0.17*	*0.10*	*0.19*	*0.23*	*0.15*	*0.14*	*0.21*	*0.13*
CD (p=0.05)	*0.77*	*0.98*	*0.60*	*0.35*	*0.50*	*0.29*	*0.55*	*0.67*	*0.42*	*0.43*	*0.64*	*0.37*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance.

Means within columns were separated by Duncan's multiple range test (DMRT).

1st reading is taken from the first week of October and the subsequent readings were taken at an interval of 21 days till the final harvest.

Table 5: Effect of different mulching materials on soil moisture percentage at 30-60 cm of Khasi mandarin

Treatments	***Soil moisture percentage at 30-60 cm (%)***								
	5th reading			***6th reading***			***7th reading***		
	2016	***2017***	***Pooled***	***2016***	***2017***	***Pooled***	***2016***	***2017***	***Pooled***
M_0: No mulch	23.20^{i}	23.60^{g}	23.40^{i}	23.35^{h}	23.77^{f}	23.56^{g}	23.34^{f}	23.85^{f}	23.60^{g}
M_1: Rice husk	26.52^{h}	27.78^{f}	27.15^{h}	26.60^{g}	27.82^{e}	27.21^{f}	26.62^{e}	27.82^{e}	27.22^{f}
M_2: Saw dust	27.90^{g}	29.68^{e}	28.79^{f}	28.25^{f}	29.75^{d}	29.00^{e}	28.40^{d}	29.85^{d}	29.13^{d}
M_3: Chopped banana leaves & pseudostem	27.45^{f}	29.22^{e}	28.33^{g}	27.92^{f}	29.43^{d}	28.68^{e}	27.85^{d}	29.42^{d}	28.64^{e}
M_4: FYM	31.30^{c}	32.15^{c}	31.73^{c}	31.17^{c}	32.26^{b}	31.71^{c}	31.45^{b}	32.35^{b}	31.90^{b}
M_5: Forest leaves	30.22^{d}	31.62^{c}	30.92^{d}	30.43^{d}	31.98^{b}	31.21^{d}	30.96^{b}	32.12^{b}	31.54^{b}
M_6: Rice straw	29.74^{e}	30.90^{d}	30.32^{e}	29.95^{e}	31.10^{c}	30.52	29.82^{c}	31.20^{c}	30.51^{c}
M_7: Transparent polythene (100μ)	34.42^{b}	35.78^{b}	35.10^{b}	34.94^{b}	36.12^{a}	35.53^{b}	34.35^{a}	36.14^{a}	35.25^{a}
M_8: Black polythene (100μ)	35.02^{a}	36.37^{a}	35.69^{a}	35.40^{a}	36.52^{a}	35.96^{a}	34.88^{a}	36.35^{a}	35.62^{a}
SEm±	*0.13*	*0.19*	*0.12*	*0.15*	*0.20*	*0.13*	*0.21*	*0.23*	*0.16*
CD (p=0.05)	*0.40*	*0.56*	*0.33*	*0.45*	*0.60*	*0.36*	*0.63*	*0.70*	*0.45*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance. Means within columns were separated by Duncan's multiple range test (DMRT).

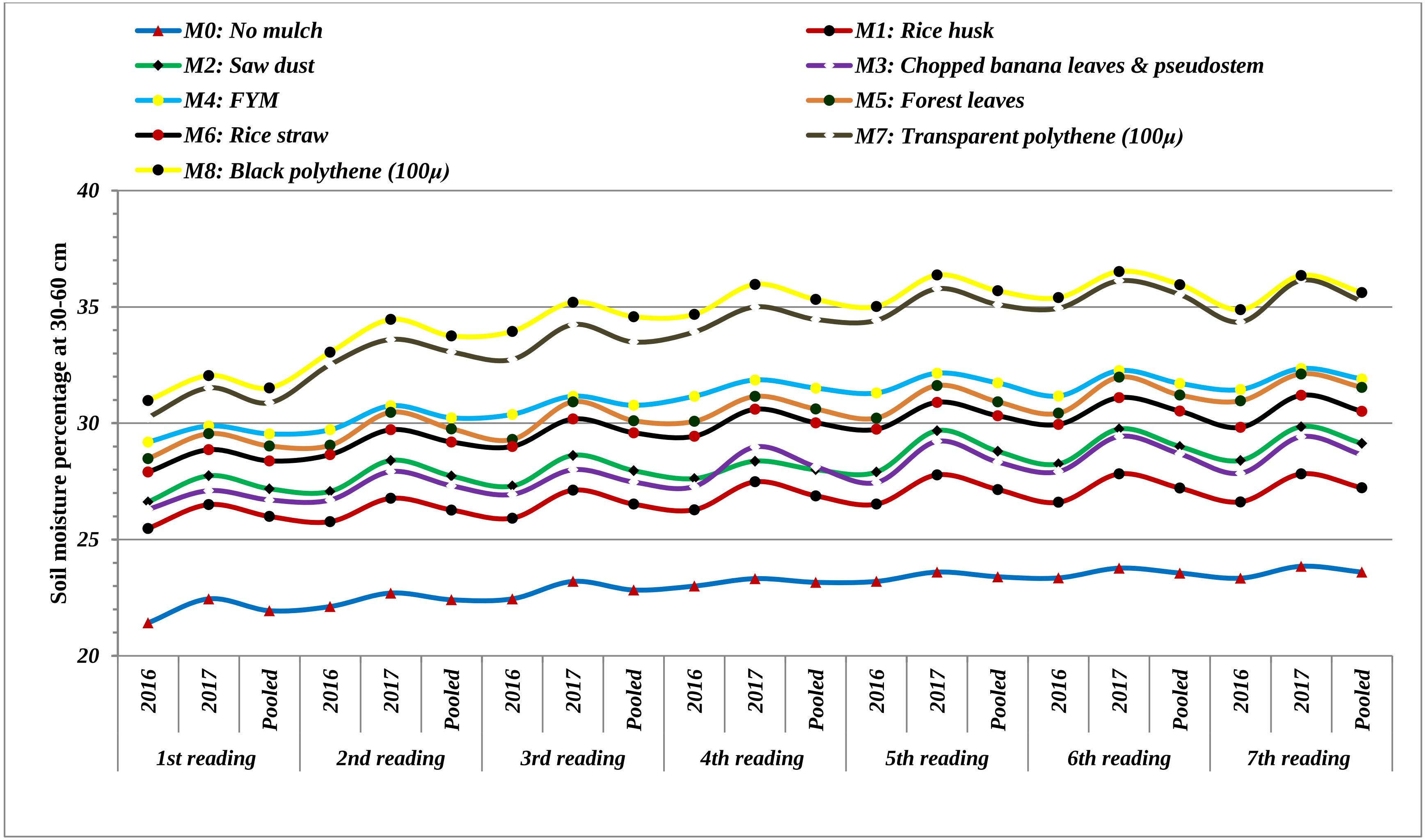

Fig 2: Effect of different mulching materials on soil moisture percentage at 30-60 cm of Khasi mandarin

difference in moisture content in the soil and was significantly higher when compare to no mulch (M_0) plots. The higher value of soil moisture content in polythene and organic mulches was due to drastic reduction of evaporation loss. The increase in soil moisture content below the mulching material in different mulch treatments could be due to reduced evaporation of soil surface moisture, enhanced infiltration percolation capacity of the soil and control in intense fluctuation of soil temperature, thus holding the moisture in the soil for longer period of time. The findings are in agreement with Kumar *et al*. (2015) who reported the highest soil moisture content in black polyethylene mulching followed by FYM and brankad mulch during two years of observation. And the least soil moisture content was recorded in control plots, which was significantly lower than all other treatments. Gosh and Bera (2015) documented that among the inorganic materials, the black polythene mulch conserved higher moisture as compared to white polythene mulch irrespective of time of sampling, in an experiment on effect of mulching on soil moisture, yield and quality of pomegranate. Shirgure (2012) reported that conservation of soil moisture was found highest in black polyethylene mulch (100 μ) and amongst the organic mulches grass mulch conserved higher moisture in acid lime. The result is also in line with Adeoye (1984) who reported high moisture content up to a depth of 60 cm in grass-mulched soil together with reduced evaporation and good infiltration.

4.1.1. Soil temperature

From the obtained results of Table 6 and 7 at 0-30 cm soil depth, it was revealed that soil temperature varied with the time of observations taken and more importantly under different mulching materials. From the pooled data we could see that soil temperature fluctuates with time interval where it starts declining from October onwards till last week of December irrespective of the mulching materials. The observations were taken on two weeks interval initiating from October first week till January where cold air temperature resulted in lowering soil temperature especially in a bare soil with no mulching

Table 6: Effect of different mulching materials on soil temperature at 0-30 cm of Khasi mandarin

Treatments	***Soil temperature at 0-30 cm (ºC)***											
	1st reading			***2nd reading***			***3rd reading***			***4th reading***		
	2016	***2017***	***Pooled***	***2016***	***2017***	***Pooled***	***2016***	***2017***	***Pooled***	***2016***	***2017***	***Pooled***
M_0: No mulch	26.76^{f}	25.26^{e}	26.01^{f}	24.12^{h}	22.65^{f}	23.38^{h}	23.32^{h}	23.65^{f}	23.49^{g}	21.95^{h}	21.98^{e}	21.97^{i}
M_1: Rice husk	29.30^{c}	27.44^{c}	28.37^{d}	27.97^{e}	26.78^{d}	27.38^{d}	26.74^{d}	27.12^{d}	26.93^{d}	25.84^{d}	25.62^{c}	25.73^{e}
M_2: Saw dust	28.35^{de}	26.17^{d}	27.26^{e}	26.86^{f}	24.80^{e}	25.83^{f}	25.42^{f}	25.66^{e}	25.54^{f}	24.30^{f}	23.46^{d}	23.88^{g}
M_3: Chopped banana leaves & pseudostem	31.57^{b}	29.68^{b}	30.63^{c}	29.05^{d}	27.17^{d}	28.11^{c}	27.82^{c}	28.52^{c}	28.17^{c}	26.75^{c}	25.68^{c}	26.21^{d}
M_4: FYM	27.76^{e}	25.96^{de}	26.86^{e}	26.12^{g}	24.76^{e}	25.44^{g}	24.15^{g}	25.56^{e}	24.85^{c}	23.85^{g}	23.20^{d}	23.53^{h}
M_5: Forest leaves	29.08^{cd}	27.22^{c}	28.15^{d}	27.86^{e}	25.88^{e}	26.87^{e}	25.84^{e}	26.75^{d}	26.30^{e}	24.94^{e}	24.95^{d}	24.95^{f}
M_6: Rice straw	31.77^{b}	30.05^{b}	30.91^{c}	29.85^{c}	27.65^{c}	28.75^{b}	28.00^{c}	28.76^{c}	28.38^{c}	26.86^{c}	26.67^{b}	26.77^{c}
M_7: Transparent polythene (100µ)	32.12^{b}	31.40^{a}	31.76^{b}	31.07^{a}	29.02^{b}	30.04^{a}	29.32^{b}	30.54^{b}	29.93^{b}	28.09^{b}	28.20^{a}	28.15^{b}
M_8: Black polythene (100µ)	33.67^{a}	31.65^{a}	32.66^{a}	31.25^{a}	29.50^{a}	30.37^{a}	30.32^{a}	31.00^{a}	30.66^{a}	28.80^{a}	28.55^{a}	28.67^{a}
SEm±	*0.30*	*0.26*	*0.20*	*0.10*	*0.15*	*0.09*	*0.13*	*0.15*	*0.10*	*0.14*	*0.20*	*0.12*
CD (p=0.05)	*0.90*	*0.76*	*0.57*	*0.29*	*0.44*	*0.26*	*0.39*	*0.45*	*0.29*	*0.40*	*0.58*	*0.34*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance.

Means within columns were separated by Duncan's multiple range test (DMRT).

1st reading is taken from the first week of October and the subsequent readings were taken at an interval of 21 days till the final harvest.

Table 7: Effect of different mulching materials on soil temperature at 0-30 cm of Khasi mandarin

Treatments	***Soil temperature at 0-30 cm (%)***								
	5th reading			***6th reading***			***7th reading***		
	2016	***2017***	***Pooled***	***2016***	***2017***	***Pooled***	***2016***	***2017***	***Pooled***
M_0: No mulch	20.45^{g}	20.50^{e}	20.47^{g}	19.62^{e}	19.82^{f}	19.72^{f}	20.42^{f}	21.35^{g}	20.89^{i}
M_1: Rice husk	23.82^{d}	24.10^{c}	23.96^{d}	22.97^{cd}	23.75^{cd}	23.36^{cd}	25.80^{c}	25.42^{cd}	25.61^{e}
M_2: Saw dust	23.32^{e}	23.12^{d}	23.22^{e}	22.78^{d}	23.28^{de}	23.03^{de}	24.25^{e}	24.38^{ef}	24.32^{g}
M_3: Chopped banana leaves & pseudostem	24.26^{c}	24.30^{c}	24.28^{d}	23.27^{c}	23.95^{c}	23.61^{c}	26.17^{c}	25.86^{c}	26.01^{d}
M_4: FYM	22.70^{f}	22.92^{d}	22.81^{f}	22.66^{d}	23.12^{e}	22.89^{e}	23.62^{e}	24.05^{f}	23.84^{h}
M_5: Forest leaves	23.80^{d}	24.00^{c}	23.90^{d}	22.85^{d}	23.70^{cd}	23.28^{cd}	24.85^{d}	24.97^{de}	24.91^{f}
M_6: Rice straw	25.72^{b}	24.50^{c}	25.11^{c}	24.87^{b}	25.88^{b}	25.37^{b}	26.68^{b}	26.85^{b}	26.77^{c}
M_7: Transparent polythene (100μ)	26.64^{a}	26.22^{b}	26.43^{b}	26.62^{a}	26.87^{a}	26.74^{a}	27.40^{a}	27.40^{b}	27.40^{b}
M_8: Black polythene (100μ)	26.85^{a}	27.00^{a}	26.92^{a}	26.70^{a}	27.03^{a}	26.87^{a}	27.75^{a}	28.24^{a}	27.99^{a}
SEm±	*0.14*	*0.20*	*0.12*	*0.12*	*0.18*	*0.11*	*0.14*	*0.20*	*0.12*
CD (p=0.05)	*0.42*	*0.58*	*0.35*	*0.35*	*0.55*	*0.31*	*0.42*	*0.60*	*0.35*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance. Means within columns were separated by Duncan's multiple range test (DMRT).

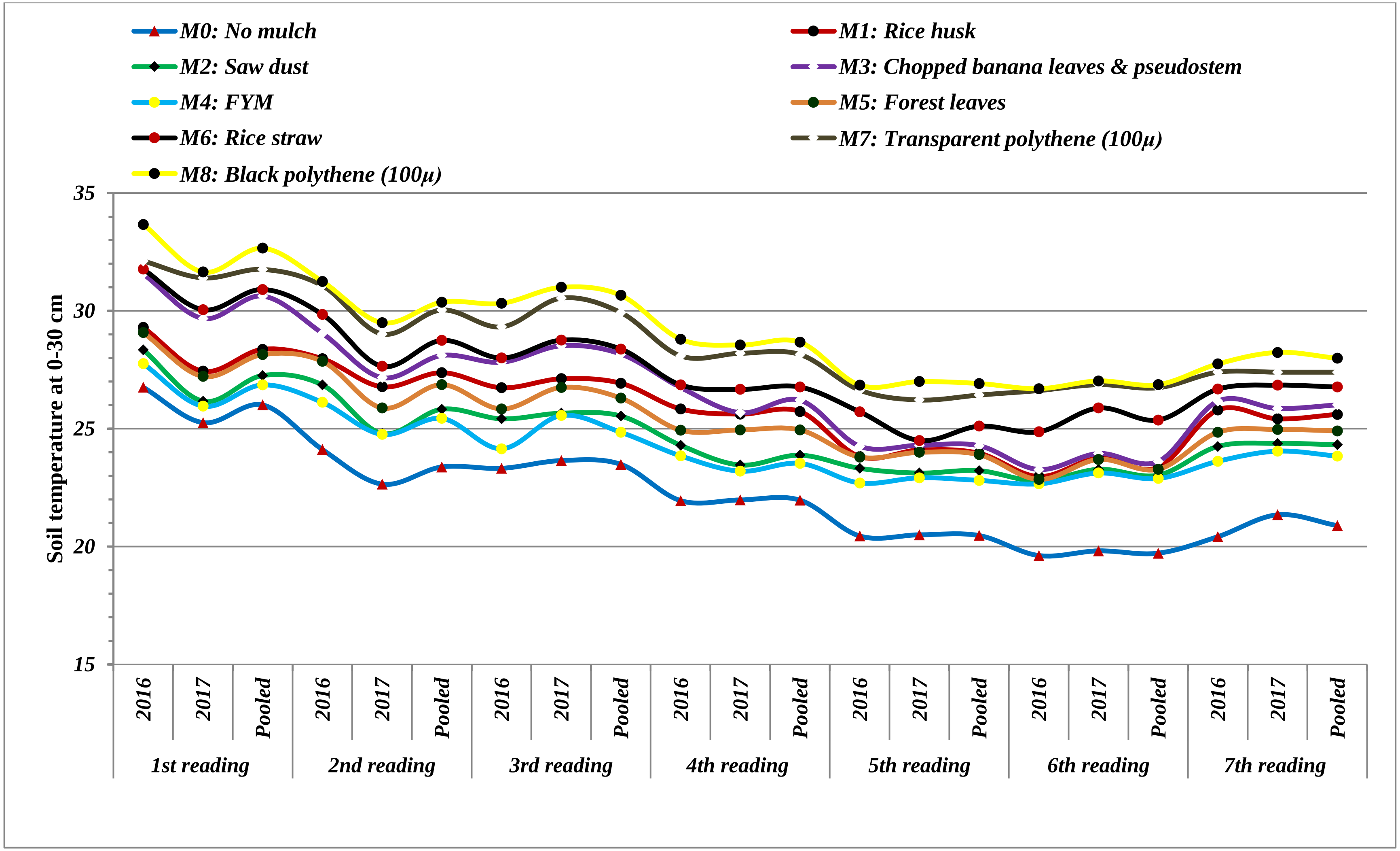

Fig 3: Effect of different mulching materials on soil temperature at 0-30 cm of Khasi mandarin

(M_0) plots. But due to mulching effects all the mulched plots maintained a relatively higher soil temperature which was statistically higher to the control plots. This higher soil temperature in mulched plots in the experiment was in agreement to the results of Choi and Chung (1997) and also with that of Hanada (1991), who stated that polythene films of transparent increased soil temperature as in comparison to grassed mulch in temperate, tropical and sub-tropical regions.

The black polythene mulch (M_8) resulted in the maximum soil temperature at all observations taken at 0-30 cm and 30-60 cm soil depths during both the seasons. In first observation the use of black polythene mulch, transparent polythene and rice straw resulted in an increase of soil temperature difference of 6.65 °C, 5.75 °C and 4.90 °C, respectively when compared with the no mulch plot. Whereas, the difference of increase soil temperature was negligible in case of FYM plots. The results acquired was in accordance to that reported by Toshio (1991) who explained that the use of plastic mulching raised the soil temperature due to suppression of latent heat loss through evaporation. The result also in line with the one reported by Jakhdhar (2010). The lower soil temperature observed in organic mulches like rice husk, saw dust, FYM and forest leaves might be due to reduced amount of radiant flux reaching the soil surface and minimizing heat loss by evaporation.

When compared the soil temperature at different depths under various mulching materials, it was observed that temperature at 0-30 cm depth was around 3 °C higher than at the 30-60 cm depth. This result was in agreement with the findings of Eruola *et al.* (2012). Again, the change in temperature during the subsequent observations at lower soil depth (30-60 cm) among the treatments showed similar trend with the higher soil profile. Generally, black polythene followed by transparent polythene and straw mulch exhibited the highest soil temperatures and the least in control plots which was significant lower to rest of the treatments.

Table 8: Effect of different mulching materials on soil temperature at 30-60 cm of Khasi mandarin

Treatments	*Soil temperature at 30-60 cm (ºC)*											
	1st reading			*2nd reading*			*3rd reading*			*4th reading*		
	2016	***2017***	***Pooled***	***2016***	***2017***	***Pooled***	***2016***	***2017***	***Pooled***	***2016***	***2017***	***Pooled***
M$_0$: No mulch	23.08^{f}	22.20^{e}	22.64^{h}	21.02^{g}	21.25^{g}	21.14^{h}	22.65^{f}	22.05^{g}	22.35^{g}	20.32^{g}	18.90^{g}	19.61^{h}
M$_1$: Rice husk	27.17^{c}	26.28^{d}	26.73^{d}	26.43^{bc}	24.38^{d}	25.40^{d}	26.25^{cd}	26.32^{d}	26.29^{d}	24.20^{d}	23.36^{de}	23.78^{e}
M$_2$: Saw dust	25.42^{d}	23.87^{e}	24.65^{f}	23.55^{e}	23.34^{e}	23.45^{f}	25.30^{e}	23.62^{f}	24.46^{f}	22.72^{f}	21.42^{f}	22.07^{g}
M$_3$: Chopped banana leaves & pseudostem	27.15^{c}	27.22^{c}	27.19^{cd}	26.20^{c}	25.17^{c}	25.68^{d}	26.85^{c}	26.40^{d}	26.63^{d}	24.64^{cd}	23.94^{cd}	24.29^{d}
M$_4$: FYM	24.47^{e}	22.68^{f}	23.58^{g}	22.88^{f}	22.50^{f}	22.69^{g}	24.80^{e}	23.14^{f}	23.97^{f}	22.32^{f}	21.10^{f}	21.71^{g}
M$_5$: Forest leaves	26.22^{d}	25.66^{d}	25.94^{e}	25.45^{d}	23.52^{e}	24.49^{e}	26.14^{d}	24.90^{e}	25.52^{e}	23.60^{e}	22.68^{e}	23.14^{f}
M$_6$: Rice straw	27.68^{bc}	27.62^{bc}	27.65^{c}	26.82^{b}	26.12^{b}	26.47^{c}	27.72^{b}	27.26^{c}	27.49^{c}	25.12^{c}	24.65^{c}	24.89^{c}
M$_7$: Transparent polythene (100µ)	28.42^{b}	28.20^{b}	28.31^{b}	27.46^{a}	26.50^{b}	26.98^{b}	28.55^{a}	28.07^{b}	28.31^{b}	26.25^{b}	25.52^{b}	25.89^{b}
M$_8$: Black polythene (100µ)	29.30^{a}	28.87^{a}	29.08^{a}	27.92^{a}	27.87^{a}	27.90^{a}	29.07^{a}	28.92^{a}	29.00^{a}	27.00^{a}	26.60^{a}	26.80^{a}
SEm±	*0.27*	*0.22*	*0.17*	*0.16*	*0.23*	*0.14*	*0.23*	*0.25*	*0.17*	*0.18*	*0.25*	*0.15*
CD (p=0.05)	*0.81*	*0.65*	*0.50*	*0.48*	*0.67*	*0.40*	*0.67*	*0.75*	*0.48*	*0.53*	*0.73*	*0.44*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance.

Means within columns were separated by Duncan's multiple range test (DMRT).

1st reading is taken from the first week of October and the subsequent readings were taken at an interval of 21 days till the final harvest.

Table 9: Effect of different mulching materials on soil temperature at 30-60 cm of Khasi mandarin

Treatments	***Soil temperature at 30-60 cm (%)***								
	5^{th} reading			***6^{th} reading***			***7^{th} reading***		
	2016	***2017***	***Pooled***	***2016***	***2017***	***Pooled***	***2016***	***2017***	***Pooled***
M_0: No mulch	19.65^{i}	18.65^{g}	19.15^{i}	17.20^{i}	18.34^{i}	17.7^{i}	18.40^{g}	19.35^{g}	18.88^{g}
M_1: Rice husk	23.67^{e}	22.38^{c}	23.03^{e}	20.67^{e}	21.42^{e}	21.05^{e}	21.34^{d}	22.70^{d}	22.02^{d}
M_2: Saw dust	22.32^{g}	20.72^{e}	21.52^{g}	19.58^{g}	20.10^{g}	19.84^{g}	20.25^{ef}	21.74^{e}	21.00^{e}
M_3: Chopped banana leaves & pseudostem	24.47^{d}	22.68^{c}	23.58^{d}	21.10^{d}	22.65^{d}	21.88^{d}	21.92^{c}	23.66^{c}	22.79^{c}
M_4: FYM	21.60^{h}	19.54^{f}	20.57^{h}	19.20^{h}	19.42^{h}	19.31^{h}	19.88^{f}	20.75^{f}	20.31^{f}
M_5: Forest leaves	22.84^{f}	21.37^{d}	22.11^{f}	20.28^{f}	20.76^{f}	20.52^{f}	20.56^{e}	22.20^{de}	21.38^{e}
M_6: Rice straw	24.85^{c}	23.82^{b}	24.34^{c}	21.70^{c}	24.16^{c}	22.93^{c}	22.87^{b}	24.84^{b}	23.85^{b}
M_7: Transparent polythene (100µ)	25.24^{b}	25.27^{a}	25.26^{b}	22.38^{b}	24.77^{b}	23.57^{b}	24.25^{a}	25.80^{a}	25.03^{a}
M_8: Black polythene (100µ)	25.82^{a}	25.72^{a}	25.77^{a}	22.80^{a}	25.68^{a}	24.24^{a}	24.80^{a}	26.02^{a}	25.41^{a}
SEm±	*0.12*	*0.17*	*0.10*	*0.12*	*0.17*	*0.10*	*0.19*	*0.23*	*0.15*
CD (p=0.05)	*0.36*	*0.50*	*0.30*	*0.36*	*0.50*	*0.30*	*0.55*	*0.70*	*0.43*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance.

Means within columns were separated by Duncan's multiple range test (DMRT).

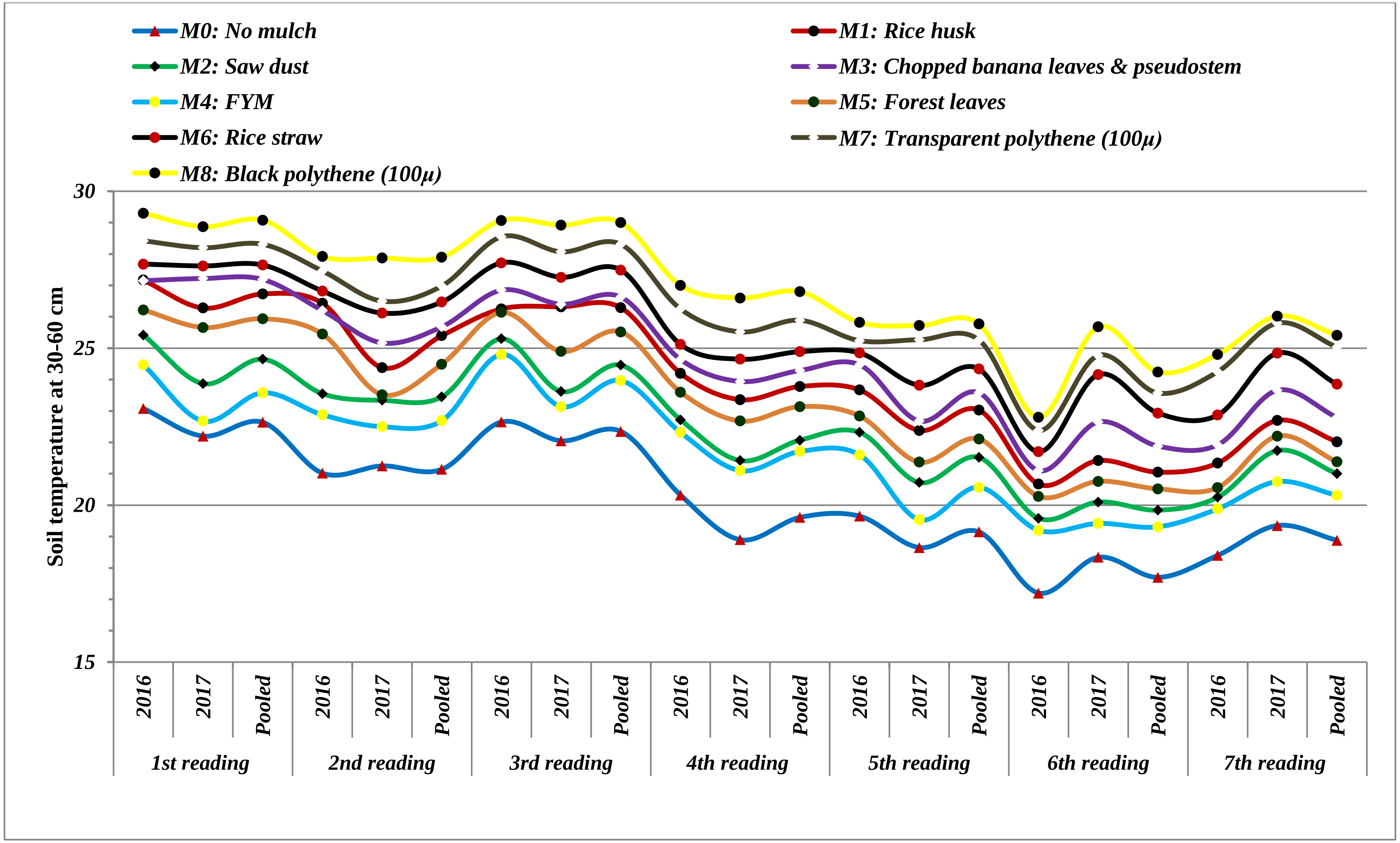

Fig 4: Effect of different mulching materials on soil temperature at 30-60 cm of Khasi mandarin

Ramakrishna *et al*. (2006) from one on-farm trials in northern Vietnam also observed that Polythene mulch increased 6 ºC and by 4 ºC in the soil temperature under Polythene mulch at 5 cm and 10 cm depth respectively. Singh *et al*. (2010) also opined that paddy straw mulch significantly increased the soil moisture status at various soil depths, which was subsequently followed by maize straw and grasses. Moreno and Moreno (2008) from their experiment concluded that the soil temperature remained always higher under polythene mulch than biodegradable films. Singh (2005) also reported that in comparison to control treatment, polythene mulch showed elevated soil temperature by 2-3 ºC and 43.7-62.5 % soil moisture content.

4.2. Effect of mulching on soil properties

The results of the various soil physico-chemical properties *viz.*, bulk density, particle density, water holding capacity, percent aggregates > 0.25 mm, soil pH, organic carbon, available N, P and K after the harvest of the fruits as influenced by different organic and inorganic mulches are presented and discussed under the following headings.

4.2.1. Effect of mulching on bulk density of the soil

The data on the effect of different mulching materials on bulk density of the soil after harvest of the fruit is presented in Table 10. The bulk density of the soil varied from 1.11 g cm^{-3} to 1.22 g cm^{-3} with an average of 1.18 g cm^{-3} in the year 2016 and 1.10 g cm^{-3} to 1.22 g cm^{-3} with an average of 1.17 g cm^{-3} in the year 2017. The highest bulk density was recorded in no mulch (M_0) recording 1.22 g cm^{-3} in both the years followed by forest leaves (M_5) recording 1.21 and 1.20 g cm^{-3} during 2016 and 2017, respectively. The lowest bulk density was recorded in saw dust (M_2) mulch with a value of 1.11 and 1.10 g cm^{-3} during 2016 and 2017, respectively. In the first year of experiment the bulk density in sawdust (M_2) and FYM (M_4) was at par and showed a significant decrease over no mulch (M_2) and forest leaves (M_5). The bulk density in rice Husk (M_1), rice straw (M_6) and transparent polythene (M_7) was at par with the

Table 10: Effect of different mulching materials on bulk density and particle density of soil on Khasi mandarin

Treatments	***Bulk density (g cm^{-3})***			***Particle density (g cm^{-3})***		
	2016	***2017***	***Pooled***	***2016***	***2017***	***Pooled***
M_0: No mulch	1.22^{a}	1.22^{a}	1.22^{a}	2.25^{a}	2.25^{a}	2.25^{a}
M_1: Rice husk	1.16^{abc}	1.14^{ab}	1.15^{bc}	2.12^{ab}	2.12^{ab}	2.12^{ab}
M_2: Saw dust	1.11^{c}	1.10^{c}	1.11^{c}	2.02^{b}	2.03^{b}	2.03^{b}
M_3: Chopped banana leaves & pseudostem	1.20^{ab}	1.19^{ab}	1.20^{ab}	2.05^{ab}	2.04^{ab}	2.04^{b}
M_4: FYM	1.13^{bc}	1.13^{bc}	1.13^{c}	2.03^{ab}	2.02^{ab}	2.03^{b}
M_5: Forest leaves	1.21^{a}	1.20^{ab}	1.20^{ab}	2.18^{ab}	2.17^{ab}	2.18^{ab}
M_6: Rice straw	1.17^{abc}	1.17^{abc}	1.17^{abc}	2.17^{ab}	2.16^{ab}	2.16^{ab}
M_7: Transparent polythene (100μ)	1.18^{abc}	1.16^{abc}	1.17^{abc}	2.22^{ab}	2.20^{ab}	2.21^{a}
M_8: Black polythene (100μ)	1.20^{ab}	1.18^{ab}	1.19^{ab}	2.22^{ab}	2.20^{ab}	2.21^{a}
SEm±	*0.02*	*0.02*	*0.02*	*0.06*	*0.07*	*0.05*
CD (p=0.05)	*0.07*	*0.07*	*0.05*	*NS*	*NS*	*NS*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance.

Means within columns were separated by Duncan's multiple range test (DMRT).

NS = Non-significant at 5% level of significance.

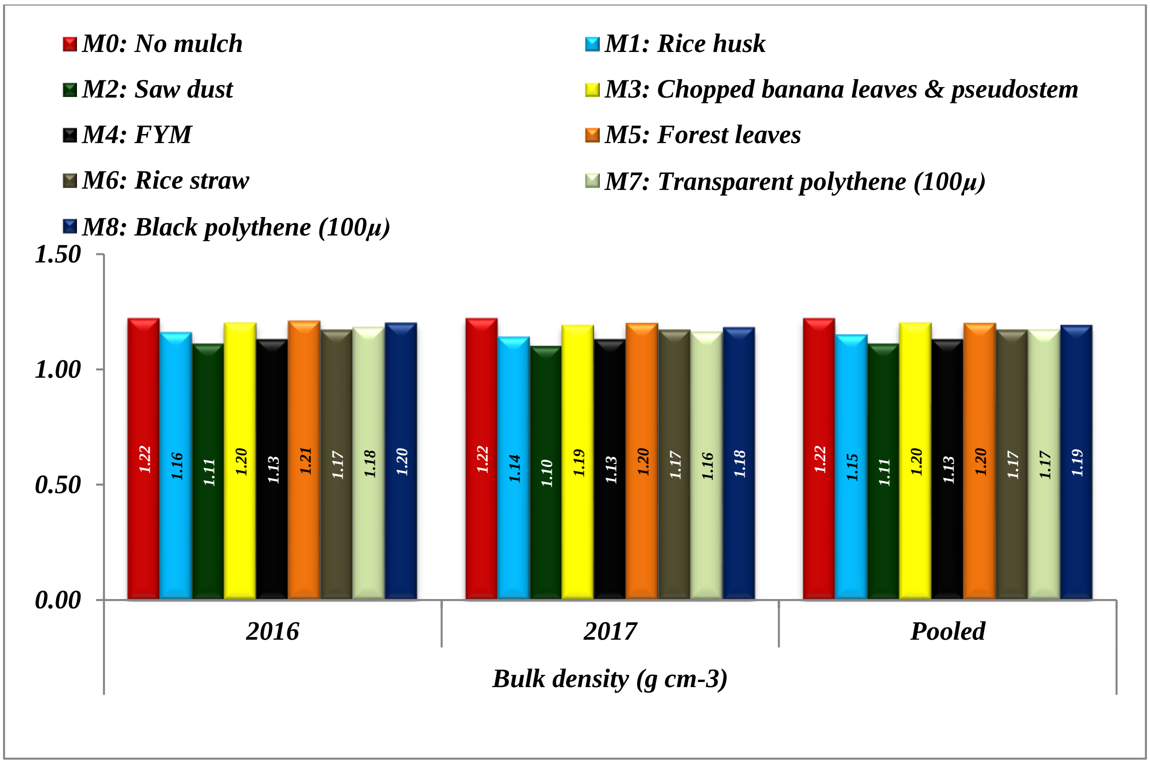

Fig 5: Effect of different mulching materials on bulk density of Khasi mandarin

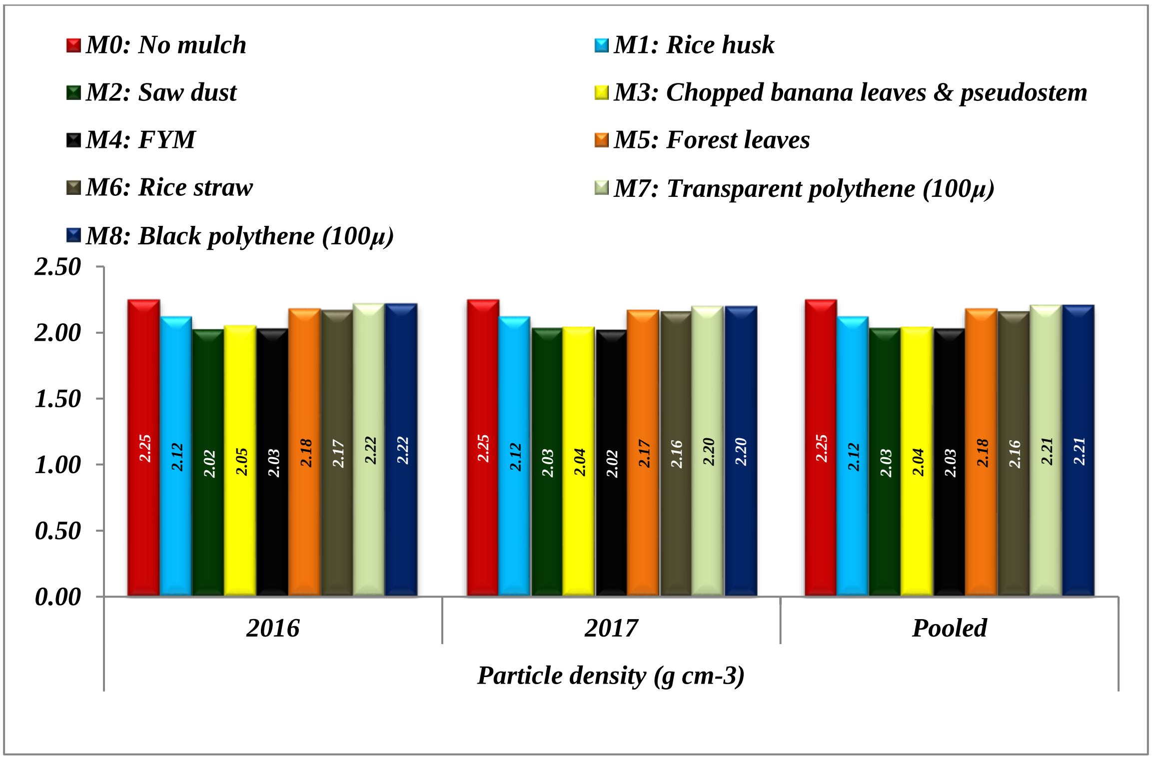

Fig 6: Effect of different mulching materials on particle density of Khasi mandarin

banana leaves & pseudo-stem (M_3), forest leaves (M_5) and black polythene (M_8) treatment was at par and showed significantly higher than sawdust (M_2). The data revealed that mulching with organic and inorganic materials had a significant decrease in bulk density over control. The above investigation is in agreement with the findings of Mathews *et al*. (2002) who expressed that use of organic materials as mulches decreased the soil bulk density. Similar records were indicated by Unger and Jones (1998), Ghuman *et al*. (2001) and Tiquia *et al*. (2002).

4.2.2. Effect of mulching on particle density of the soil

The effect of mulching on particle density of the soil is presented in Table 10. In both the years, the highest particle density (2.25 g cm^{-3}) was recorded in no mulch (M_1) followed by black polythene (M_8) and transparent polythene (M_7) which recorded 2.22 and 2.20 g cm^{-3} in 2016 and 2017, respectively. While the minimum (2.02 g cm^{-3}) was observed in treatment saw dust (M_2) and FYM (M_4) mulch during 2016 and 2017. The particle density due to addition of mulching did not show any significant difference after two years of treatment with various organic and inorganic mulching materials.

4.2.3. Effect of mulching on maximum water holding capacity of the soil

The data on the effect of mulching on maximum water holding capacity (WHC) in soil is presented in Table 11. The maximum WHC of the soil varied from 27.12 to 33.15 % and 28.25 to 34.25 % during 2016 and 2017, respectively. The maximum WHC was recorded in black polythene treatment and minimum was recorded in control.

The maximum WHC recorded in the second year of experiment further increased in all the treatments. The maximum water holding capacity in saw dust (M_2), transparent polythene (M_7) and black polythene (M_8) treatment was at par and showed a significant increase over no mulch (M_0) and forest leaves (M_5). The results obtained, showed that maximum WHC in rice husk (M_1) and rice straw (M_6) was at par and did not differ significantly with the other

Table 11: Effect of different mulching materials on maximum water holding capacity and percent aggregates of soil on Khasi mandarin

Treatments	***Water holding capacity (%)***			***Percent aggregates >0.25mm (%)***		
	2016	***2017***	***2016***	***2017***	***2016***	***2017***
M_0: No mulch	27.12^{c}	28.25^{c}	27.69^{c}	62.05^{c}	62.15^{c}	62.10^{c}
M_1: Rice husk	30.54^{abc}	31.32^{abc}	30.93^{bc}	68.22^{abc}	68.57^{abc}	68.40^{a}
M_2: Saw dust	32.58^{a}	32.87^{a}	32.73^{ab}	68.65^{ab}	68.90^{ab}	68.78^{a}
M_3: Chopped banana leaves & pseudostem	31.15^{ab}	32.90^{ab}	32.03^{ab}	64.60^{bc}	65.35^{bc}	64.98^{bc}
M_4: FYM	31.80^{ab}	32.38^{ab}	32.09^{ab}	69.38^{a}	70.20^{a}	69.79^{a}
M_5: Forest leaves	28.74^{bc}	30.42^{bc}	29.58^{bc}	67.54^{abc}	67.37^{abc}	67.45^{ab}
M_6: Rice straw	29.62^{abc}	29.56^{abc}	29.59^{bc}	66.76^{abc}	67.48^{abc}	67.12^{ab}
M_7: Transparent polythene (100μ)	32.35^{a}	33.23^{a}	32.79^{ab}	63.70^{c}	64.10^{c}	63.90^{c}
M_8: Black polythene (100μ)	33.15^{a}	34.25^{a}	33.70^{a}	64.92^{abc}	64.37^{bc}	64.64^{bc}
SEm±	*1.08*	*1.03*	*0.74*	*1.40*	*1.34*	*0.97*
CD (p=0.05)	*3.20*	*3.05*	*2.14*	*4.15*	*3.98*	*2.77*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance.

Means within columns were separated by Duncan's multiple range test (DMRT).

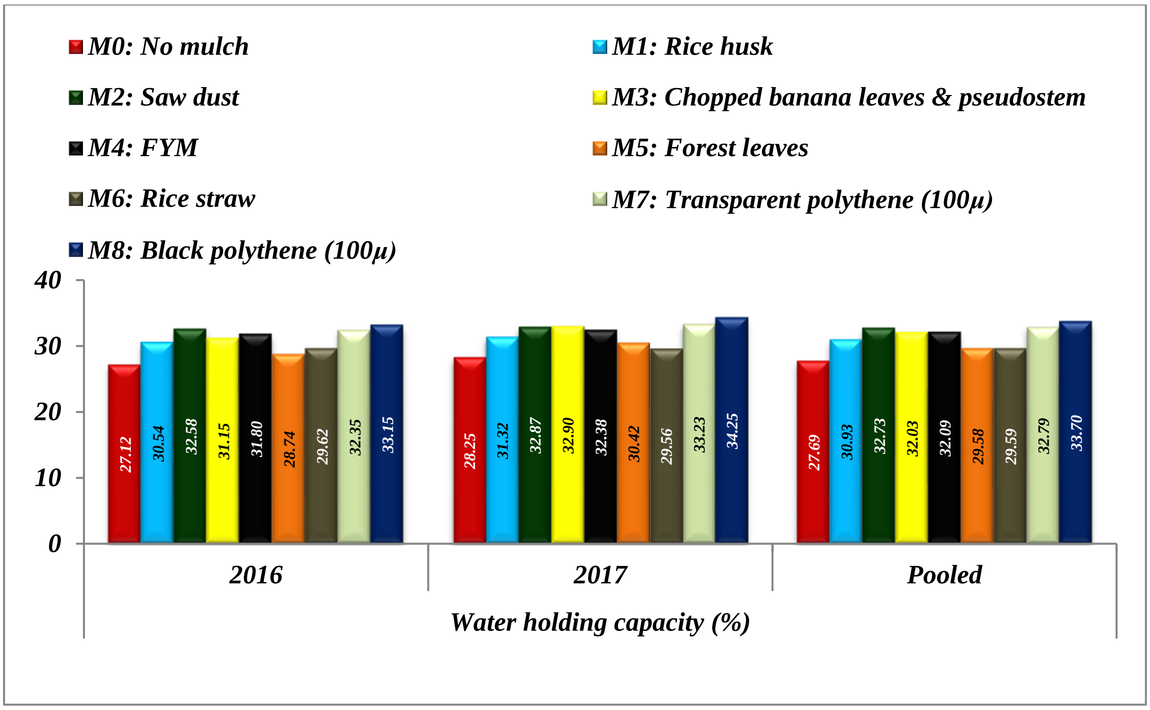

Fig 7: Effect of different mulching materials on maximum water holding capacity of Khasi mandarin

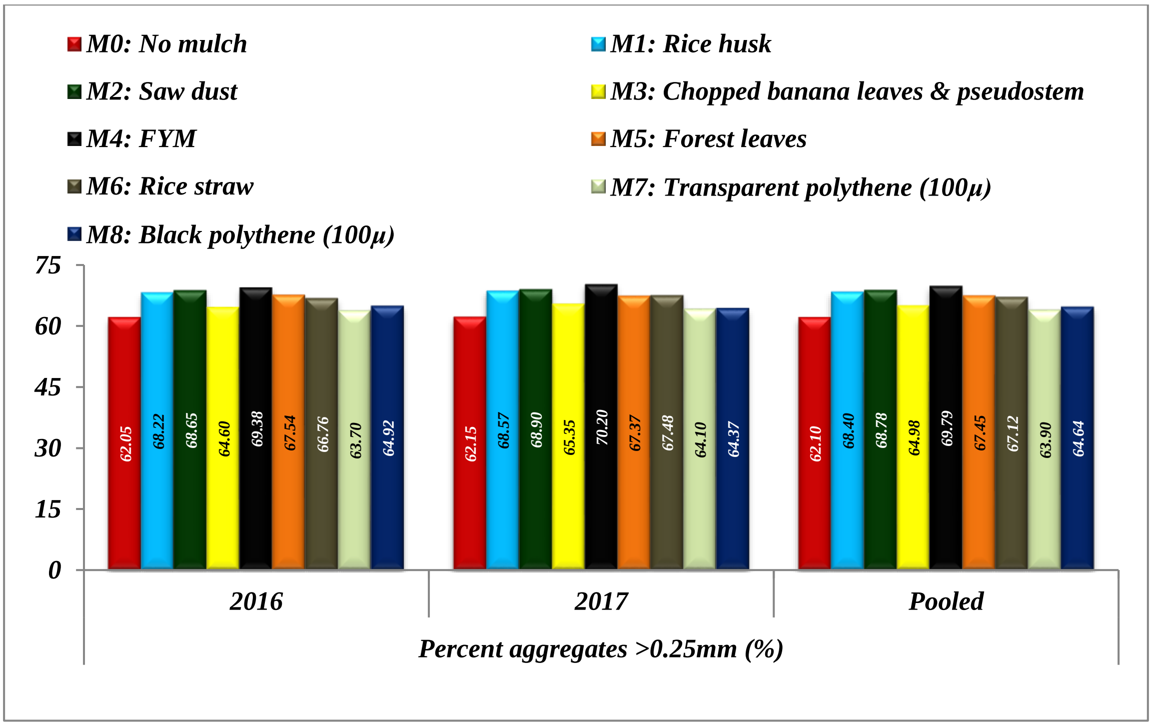

Fig 8: Effect of different mulching materials on percent aggregates of Khasi mandarin

treatments. However, the maximum WHC in chopped banana leaves & pseudo-stem (M_3) was at par with FYM (M_4) treatment and was significantly higher than no mulch (M_0). The data revealed that maximum water holding capacity showed similar trend in both the experimental years.

The data revealed that mulching with various materials brought about a significant increase in maximum water holding capacity of soil as compared to control. The application of black polythene, transparent polythene, saw dust and FYM resulted an increase of 21.70, 18.42, 18.20 and 15.89 % in maximum water holding capacity of the soil, respectively as compared to control. The increase in maximum water holding capacity of the soil with different mulching materials could be due to reduction in evaporation loss and increase in organic matter content and improvement in its physical properties of the soil. These findings are in accordance with the findings of Laxminarayana (2006) who reported that, the application of organic manures improved the maximum water holding capacity of the soil. Similar results were also reported by Singh *et al.*, 2006.

4.2.4. Effect of mulching on percent aggregates > 0.25 mm

The effect of mulching on percent aggregates > 0.25 mm of soil is presented in Table 11. The highest percent aggregates > 0.25 mm i.e. 69.38 and 70.20 were recorded in FYM (M_4) treatment in 2016 and 2017, respectively followed by saw dust (M_2) mulch. The lowest percent aggregates > 0.25 mm (62.05 and 62.15 %) were found in no mulch (M_0) during 2016 and 2017 respectively with the mean as 62.10 %. In the first experimental year the percent aggregates > 0.25 mm in FYM (M_4), saw dust (M_2), rice husk (M_1), forest leaves (M_5), rice straw (M_6) and black polythene (M_8) was at par. The percent aggregates > 0.25 mm in transparent polythene (M_7) and no mulch (M_0) was found to be at par and significantly lower than FYM (M_4) and saw dust (M_2). The percent aggregates > 0.25 mm in rice husk (M_1), forest leaves (M_5), rice straw (M_6) and black polythene (M_8) was at par. In the succeeding year of experiment no mulch (M_0), chopped banana leaves & pseudo-stem (M_3), transparent polythene (M_7) and black polythene (M_8) was at par and showed significant decrease over FYM. Further, percent aggregates > 0.25 mm in rice husk (M_1), saw dust (M_2), FYM (M_4), forest leaves (M_5) and rice straw (M_6) did not differ significantly. The data revealed that addition of addition of rice husk, saw dust, FYM, forest leaves and rice straw caused a significant increase in percent aggregates > 0.25 mm over no mulch treatments in both the years. The addition of FYM, saw dust, and rice husk caused an increase of 12.38, 10.76 and 10.14 % in percent aggregates > 0.25 mm as compared to no mulch, respectively.

The higher percent aggregation in these treatments might be because of higher organic matter content due to incorporation of organic materials as mulches and that together with clay and other soil constituents favour particle aggregation. Pinamonti *et al*. (1995) also opined that simple mulch like straw showed increase in soil aggregate stability. Selvi *et al*. (2003) also corroborated that application of FYM along with NPK fertilizers results in significant increase in the water stable aggregates.

4.2.5. Effect of mulching on soil pH

The data recorded on soil pH of different mulching materials showed that there was variation in the data analysed during the two years of investigation. The highest soil pH was 5.03 and 5.07 observed in no mulch (M_0) during 2016 and 2017 with a mean of 5.05, followed by black polythene (M_8) mulch which showed a pH of 4.95 and 4.93, respectively. Among the different treatments, minimum soil pH was 4.82 and 4.68 which was recorded in treatment FYM (M_4) during 2016 and 2017, respectively with mean value as 4.75. In the first year of experiment the variation in the soil pH was not significant however in the subsequent year of experiment soil pH showed a significant decrease in all the treatments except in rice husk (M_1), transparent polythene (M_7) and black polythene (M_8) over control. The soil pH during 2017-18 in FYM (M_4) and

Table 12: Effect of different mulching materials on soil pH and organic carbon of soil on Khasi mandarin

Treatments	*Soil pH*			*Organic carbon (%)*		
	2016	***2017***	***2016***	***2017***	***2016***	***2017***
M_0: No mulch	5.03^{a}	5.07^{a}	5.05^{a}	2.52^{d}	2.54^{d}	2.53^{d}
M_1: Rice husk	4.90^{ab}	4.88^{ab}	4.89^{bc}	2.75^{bc}	2.77^{bc}	2.76^{bc}
M_2: Saw dust	4.83^{b}	4.75^{bc}	4.79^{c}	2.96^{ab}	2.97^{ab}	2.96^{ab}
M_3: Chopped banana leaves & pseudostem	4.87^{b}	4.83^{bc}	4.85^{bc}	2.68^{bc}	2.70^{bc}	2.69^{bc}
M_4: FYM	4.82^{b}	4.68^{c}	4.75^{c}	3.06^{a}	3.08^{a}	3.07^{a}
M_5: Forest leaves	4.83^{b}	4.70^{c}	4.76^{c}	2.87^{ab}	2.90^{ab}	2.88^{ab}
M_6: Rice straw	4.86^{b}	4.82^{b}	4.84^{bc}	2.66^{c}	2.68^{c}	2.67^{c}
M_7: Transparent polythene (100μ)	4.92^{ab}	4.90^{ab}	4.91^{bc}	2.64^{cd}	2.66^{cd}	2.65^{cd}
M_8: Black polythene (100μ)	4.95^{ab}	4.93^{ab}	4.94^{ab}	2.56^{d}	2.59^{d}	2.58^{d}
SEm±	*0.05*	*0.07*	*0.04*	*0.07*	*0.06*	*0.04*
CD (p=0.05)	*NS*	*0.20*	*0.12*	*0.20*	*0.18*	*0.13*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance.

Means within columns were separated by Duncan's multiple range test (DMRT).

NS = Non-significant at 5% level of significance.

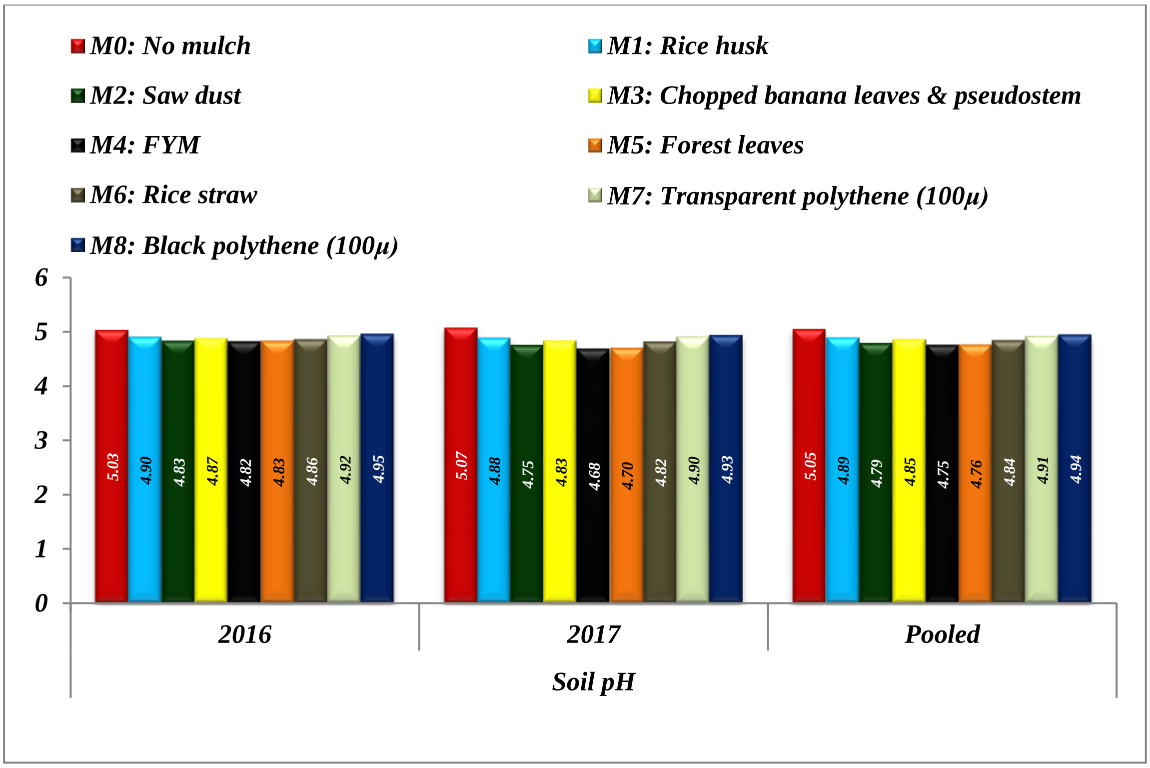

Table 9: Effect of different mulching materials on soil pH of soil on Khasi mandarin

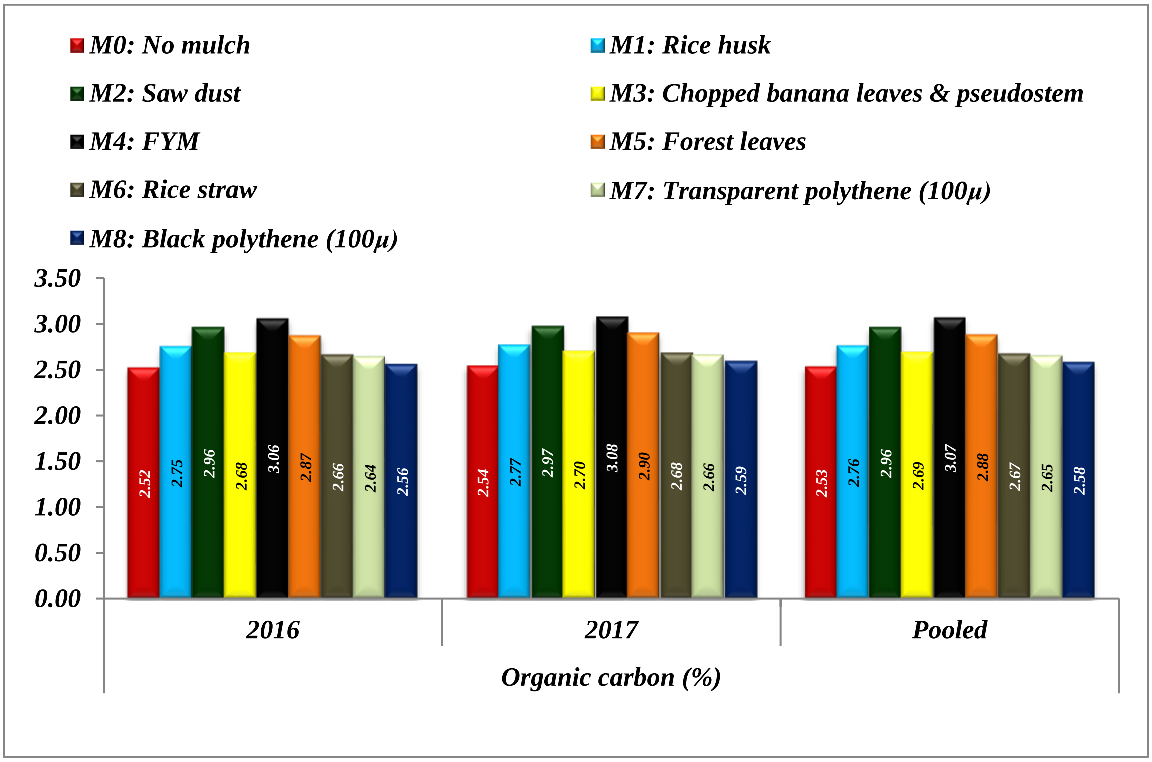

Table 10: Effect of different mulching materials on organic carbon of soil on Khasi mandarin

forest leaves (M_5) was at par and showed significant decrease over no mulch (M_0), rice husk (M_1), transparent polythene (M_7) and black polythene (M_8). While soil pH in saw dust (M_2), chopped banana leaves & pseudo-stem (M_3) and rice straw (M_6) was at par and showed significantly lower than no mulch (M_0). However, pH in saw dust (M_2), chopped banana leaves & pseudo-stem (M_3), FYM (M_4), forest leaves (M_5) and rice straw (M_6) did not differ significantly.

The decrease in soil pH could be due to release of organic acids which is from the decomposition of mulches. The present findings are in agreement with Lalitha *et al.* (2010) who cited that decomposition of organic residues under plastic mulch increases the organic acids to the soil. This was also supported by Hild and Morgan (1993), Himelick and Watson (1990) and Billeaud and Zajicek (1989) as they concluded that use of organic mulches resulted in reduce of underlying soil pH. Similarly, Kumar (2014) also documented that the lowest soil pH was recorded in maize straw tree basin mulch and the highest soil pH in no mulch treatment in two years of continuous experiment. Use of plastic-film mulch decreased soil pH and the decrease in soil pH which was associated with elevated soil nitrate content resulting as an effect of mineralization of nitrogen due to upsurge in soil moisture and temperature under plastic mulch (Wang *et al*., 2017).

4.2.6. Effect of mulching on organic carbon of the soil

The organic carbon content of the soil varied from 2.52 to 3.06 % and 2.54 to 3.08 % with a mean of 2.74 and 2.77 % during 2016 and 2017, respectively (Table 12). The highest organic carbon was found in FYM (M_4) mulch followed by saw dust and forest leaves treatments whereas the lowest was in no mulch treatment in both the years of investigation. Application of rice husk (M_1), saw dust (M_2), FYM (M_4) and forest leaves (M_5) recorded a significant increase in organic carbon content of the soil as compared to no mulch (M_0). The soil organic carbon in FYM (M_4) treatment was significantly higher than rice husk (M_1), chopped banana leaves & pseudostem (M_3), rice straw (M_6), transparent polythene (M_7), and black polythene (M_7) treatments during 2016 and 2017.

The data revealed that addition of rice husk, saw dust, FYM and forest leaves caused a significant increase in organic carbon content in the soil. The increase in organic carbon content in FYM was 18.99, 15.85, 14.98, 14.13 and 11.23% higher than black polythene, transparent polythene, rice straw, chopped banana leaves & pseudostem and rice husk, respectively.

The increase in organic carbon content of the soil could be due to topping of the soil with various mulches, as a result it developed a better habitat for soil organisms impeding erosions of wind and water, countering fluctuations in temperature and relative humidity and also increasing the content of organic matter as nutrition source and ultimately enhancing. The present finding was in conformity with Kumar (2014), who reported that under different organic mulch treatment the highest soil organic carbon content was observed in FYM mulch. Gu *et al.* (2016) found in their study that mulching with straw and grass in the sloping land of citrus orchard showed a significant increased in soil organic carbon content. Kar and Kumar (2007) also opined that, the mulch increased important available nutrients and organic carbon which resulted in better crop growth and yield.

4.2.7. Effect of mulching on available Nitrogen (N)

The available N in the soil ranged from 363.88 to 525.95 kg ha^{-1} and 363.17 to 524.28 kg ha^{-1} in 2016 and 2017 respectively (Table 13). In both the years the highest available N was found in FYM (M_4) followed by forest leaves (M_5) and the lowest was observed in no mulch (M_0). The available N content in rice husk (M_1) and rice straw (M_6) treatment was at par and significantly lower than FYM (M_4). The available N content in saw dust (M_2), transparent polythene (M_7) and black polythene (M_8) treatment was at par and significantly higher over control (M_0). Further available N content in transparent polythene

Table 13: Effect of different mulching materials on available nitrogen, phosphorus and potassium of Khasi mandarin

Treatments	***Available nutrients***								
	Nitrogen (kg ha^{-1})			***Phosphorus (kg ha^{-1})***			***Potassium (kg ha^{-1})***		
	2016	***2017***	***Pooled***	***2016***	***2017***	***Pooled***	***2016***	***2017***	***Pooled***
M_0: No mulch	363.88^{f}	363.17^{f}	363.53^{f}	10.86^{e}	10.78^{d}	10.82^{f}	184.60^{e}	182.22^{e}	183.41^{e}
M_1: Rice husk	489.80^{bc}	488.67^{bc}	489.23^{bc}	20.10^{a}	19.96^{a}	20.03^{ab}	289.82^{ab}	289.85^{ab}	289.84^{ab}
M_2: Saw dust	474.95^{cd}	474.40^{cd}	474.68^{cd}	16.16^{bc}	15.86^{bc}	16.01^{c}	251.62^{cd}	251.62^{cd}	251.62^{cd}
M_3: Chopped banana leaves & pseudostem	436.67^{e}	437.02^{e}	436.84^{e}	15.22^{cd}	15.72^{bc}	15.47^{cd}	243.02^{d}	243.69^{d}	243.36^{d}
M_4: FYM	525.95^{a}	524.28^{a}	525.12^{a}	21.20^{a}	20.57^{a}	20.89^{a}	319.88^{a}	320.54^{a}	320.21^{a}
M_5: Forest leaves	511.22^{ab}	511.42^{ab}	511.32^{ab}	19.42^{ab}	20.02^{ab}	19.72^{ab}	269.08^{bc}	270.20^{bc}	269.64^{bc}
M_6: Rice straw	487.18^{bc}	488.32^{bc}	487.75^{bc}	18.40^{ab}	18.53^{ab}	18.46^{b}	308.60^{a}	309.52^{a}	309.06^{a}
M_7: Transparent polythene (100μ)	454.10^{de}	453.94^{cd}	454.02^{de}	11.92^{de}	12.50^{d}	12.21^{ef}	267.94^{bc}	268.26^{bc}	268.10^{bc}
M_8: Black polythene (100μ)	446.05^{de}	445.77^{de}	445.91^{e}	13.65^{de}	13.32^{cd}	13.49^{de}	278.90^{b}	278.48^{b}	278.69^{b}
SEm±	*10.15*	*11.28*	*7.59*	*1.07*	*1.02*	*0.74*	*7.62*	*7.04*	*5.19*
CD (p=0.05)	*30.17*	*33.51*	*21.76*	*3.18*	*3.03*	*2.12*	*22.65*	*20.93*	*14.88*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance. Means within columns were separated by Duncan's multiple range test (DMRT).

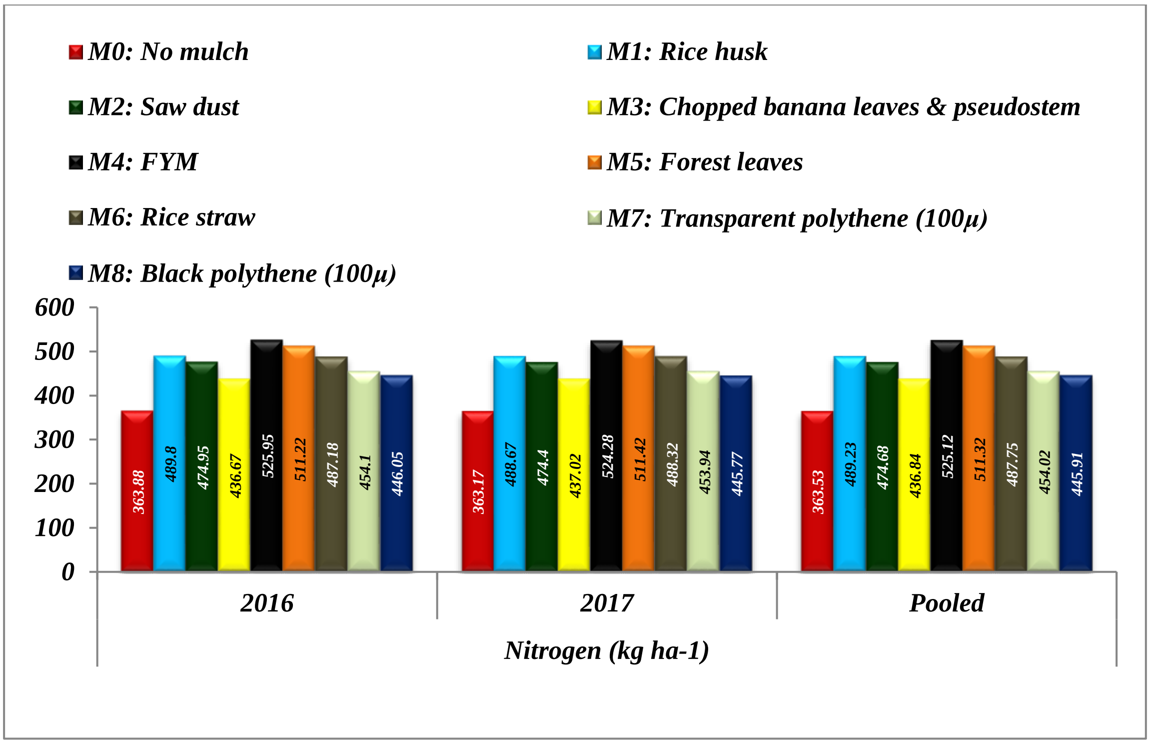

Fig 11: Effect of different mulching materials on available nitrogen of Khasi mandarin

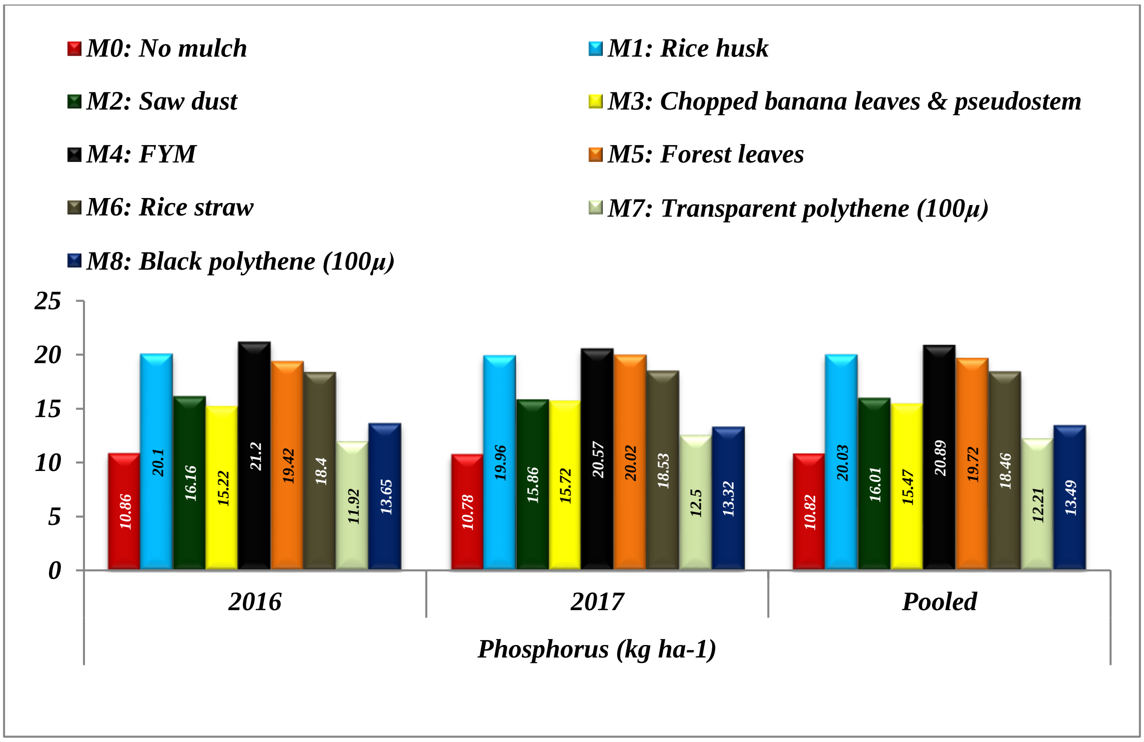

Fig 12: Effect of different mulching materials on available phosphorus of Khasi mandarin

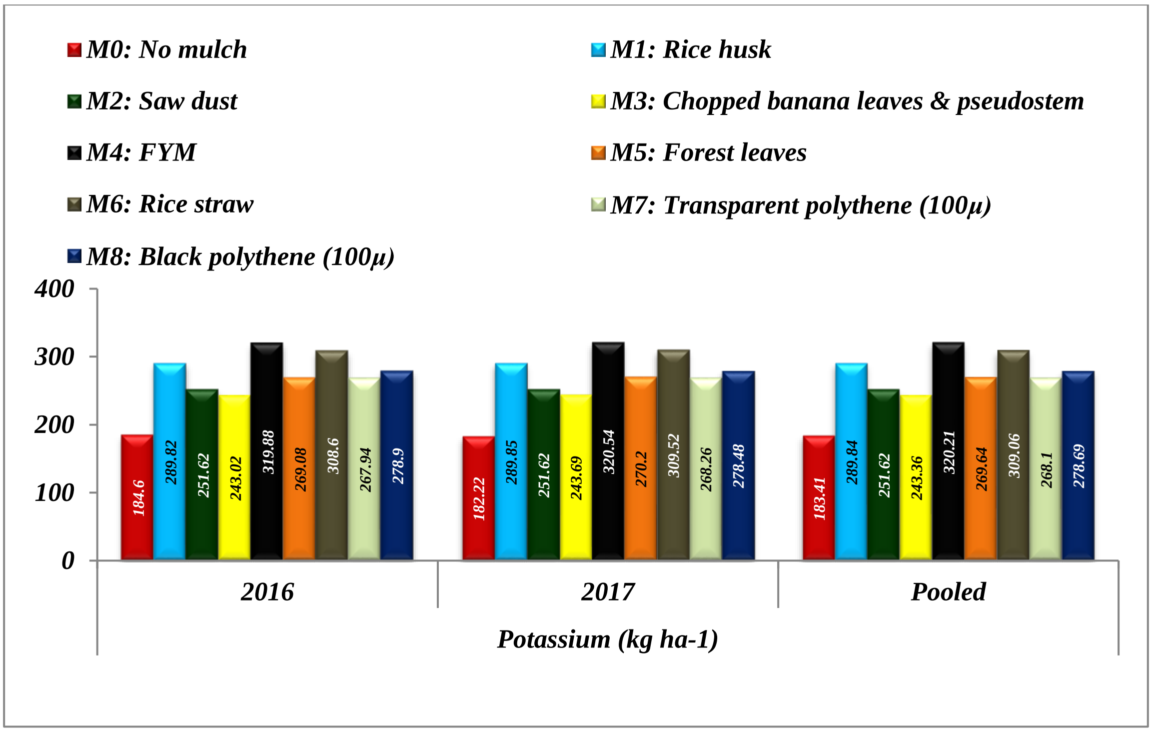

Fig 13: Effect of different mulching materials on available potassium of Khasi mandarin

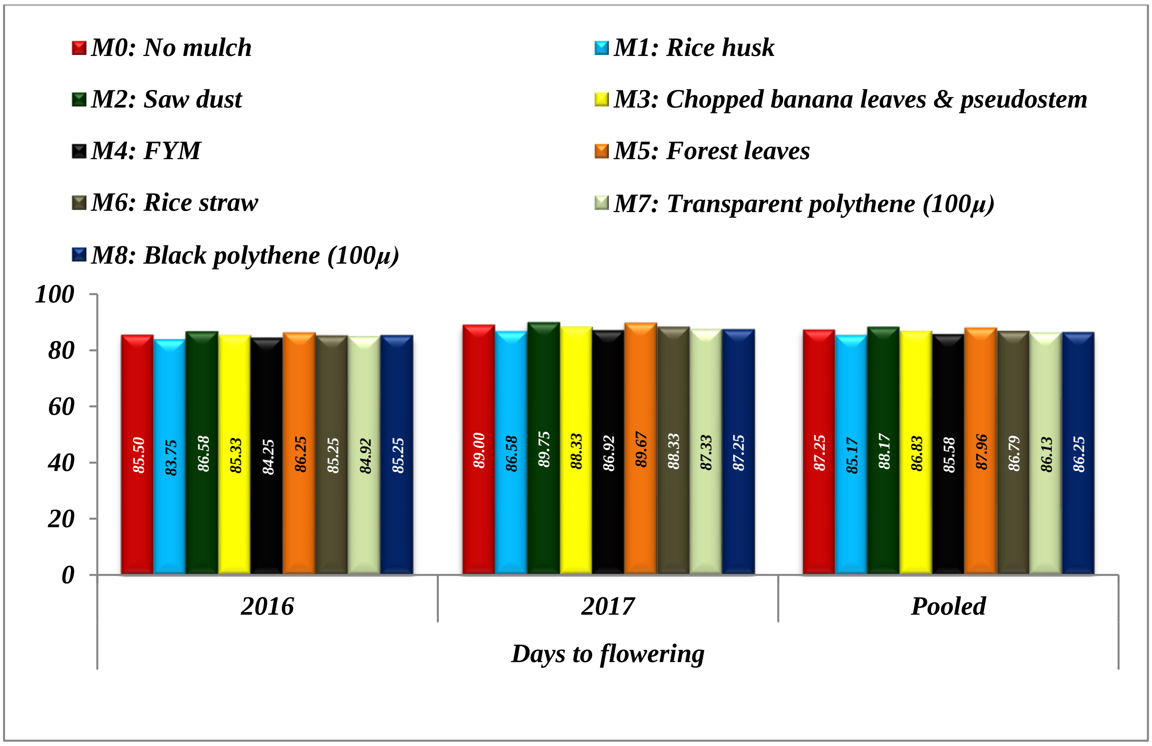

Fig 14: Effect of different mulching materials on days to flowering of Khasi mandarin

(M_7) and black polythene (M_8) treatment was at par with chopped banana leaves & pseudostem (M_3) and it decreased significantly as compared to FYM (M_4). The available N content in rice husk (M_1), forest leaves (M_5) and rice straw (M_6) treatment was at par and found to be significantly higher than chopped banana leaves & pseudostem (M_3). However in the succeeding year the available N content in transparent polythene (M_7) treatment was at par with saw dust (M_2) and rice straw (M_6) and found to be significantly higher over chopped banana leaves & pseudostem (M_3) and no mulch (M_0).

The data revealed that application of organic and inorganic mulch caused a significant increase in available N in soil as compared to control in both the years of experiments. The increase in available N in FYM, forest leaves, rice husk and rice straw was 30.77, 28.98, 25.69 and 25.47 % higher over no mulch, respectively.

The increase in available nitrogen in soils after the harvest of the fruit maybe due to incorporation of organic and inorganic sources, increased microbial activity and also favourable condition for micro organisms beneath the mulching materials, which may have lead to improve the nitrification process. Das and Dutta (2018) studied effect of mulching on soil properties in Mango orchard using black polythene and different organic mulching materials and stated that the important soil mineral contents (nitrogen, phosphorus and potassium) were influenced by incorporation of different organic and inorganic mulches. Application of different organic mulching materials under rainfed condition of Shiwalik foothills of Himalayas showed that the highest available nitrogen was found in the treatment FYM mulch (Kumar, 2014). Mahmoud and Sheren (2014) also corroborated that use of organic and inorganic mulches increased the soil mineral content.

4.2.8. Effect of mulching on available Phosphorus (P)

The experimental results pertaining to available phosphorus showed that there was a significant difference among the treatments (Table 13). Perusal of data revealed that, maximum available phosphorus was found under FYM (M_4) mulch during 2016 and 2017 respectively, with a value of 21.20 and 20.57 kg ha^{-1}, which was followed by rice husk (M_2) treatment in the first experimental year (20.10 kg ha^{-1}) however, in the second experimental year the second highest available phosphorus was recorded in the forest leaves (M_2) mulch (20.02 kg ha^{-1}), and the minimum available phosphorus of 10.86 and 10.78 kg ha^{-1} was recorded under no mulch (M_0) during 2016 and 2017, respectively, with mean of 10.82 kg ha^{-1}. The available P content in forest leaves (M_5), rice straw (M_6) was at par with rice husk (M_1) and FYM (M_4) treatments and showed a significant increase over chopped banana leaves & pseudostem (M_3). Whereas, the available P content in saw dust (M_2) was at par with chopped banana leaves & pseudostem (M_3). The available P content in transparent polythene (M_7), black polythene (M_8) and no mulch (M_0) treatment did not differ significantly and showed a significant decrease over saw dust (M_2). And the available P content during 2017-18 showed that black polythene (M_8) treatment was at par with saw dust (M_2) and chopped banana leaves & pseudostem (M_3).

The data revealed that addition of organic mulches caused a significant increase in available P content as compared to inorganic mulches and no mulch. Application of FYM, rice husk, forest leaves and rice straw caused an increase of 48.20, 45.98, 45.13 and 41.39 % available P in soils as compared to no mulch treatment. Dahiya and Malik (2002) opined that the production of organic acids during the decomposition of organic mulches facilitates in solubilizing the inherent P through the presence of metal cations like calcium, aluminium and iron and thus aids in reducing the sorption of P. In an experiment of comparison of mulched and no mulched treatment the treatment under mulched showed significant availability of phosphorus nutrient (Green & Rakow, 1995). Qu *et al.* (2019) also revealed that using of green waste compost as mulching material showed a significant increase in the available phosphorus content.

4.2.9. Effect of mulching on available Potassium (K)

The result recorded during 2016 showed that available potassium was highest in FYM (M_4) mulch (319.88 kg ha^{-1}), which was followed by rice straw (M_6) mulch (308.60 kg ha^{-1}) and the lowest was recorded in no mulch (M_0) (184.60 kg ha^{-1}). In 2017 also, the highest available potassium was found in FYM (M_4) mulch followed by rice straw (M_6) mulch with a value of 318.87 and 307.86 kg ha^{-1}, respectively and the minimum was recorded 182.22 kg ha^{-1} in no mulch (M_0). The available K content in FYM (M_4), rice straw (M_6) and rice husk (M_1) treatment was at par and showed a significant increase over saw dust (M_2) and chopped banana leaves & pseudostem (M_3). The available K content in forest leaves (M_5), transparent polythene (M_7) and black polythene (M_8) treatment did not differ significantly. Further, available K in rice husk (M_1) and forest leaves (M_5) were significantly higher as compared to no mulch (M_0). Again, available K in saw dust (M_2) and transparent polythene (M_7) was at par. The available K content showed similar trend even in the second year of the research.

The data revealed that addition of all the organic and inorganic mulches brought about a significant increase in available K as compared no mulch. The increase in available K in FYM, rice straw, rice husk and black polythene was 42.72, 40.66, 36.72 and 34.19 % higher over no mulch treatment, respectively. Alharbi (2017) found in his study that available potassium in surface soil for mulched treatment was higher than the soil devoid of mulch treatment by 27.6 and 20 % in the beginning and end season. Broschat (2007) also reported that plots mulched with organic materials had significantly increased soil K concentrations than the unmulched plots. Increasing amounts of available soil potassium and phosphorus was observed under mulches (Tukey and Schoff, 1963).

4.3. Effect of mulching on plant performance of Khasi Mandarin (*Citrus reticulata* Blanco)

4.3.1. Effect of mulching on yield attributes

The outcome of the various yield parameters *viz.*, days to flowering, fruit size (cm^2), fruit weight (g), fruit yield/ tree (kg) and projected yield (q/ha) as influenced by different organic and inorganic mulches during the crop growth are discussed.

The fruit yield is an outcome of various biological interactions which involves morphological, physiological and biochemical changes that occurs during the growth and development of a tree (Donald, 1962).

The upsurge in yield parameters under the mulching treatments may be attributed to better root activity by amassing the feeder roots up to the soil, thus minimising the competition for water and nutrients to the plants subsequently which may have helped in improving the structure of the soil by reducing the runoff and erosion (Jaganath, 1998). Mulches reduces soil moisture evaporation rate and maintains soil temperature for better uptake of water and nutrients by plants.

4.3.1.1. Effect of mulching on days to flowering

The data on the days taken for flowering are presented in Table 14. A perusal of the data revealed that the number of days taken to flowering among the treatments did not significantly differ with reference to the mulched materials used. The result is in close conformity with the findings of Lalruatsangi and Hazarika (2018) and Shirgure (2012) in Acid lime, who cited that the effect of different mulches did not record any significant variations in regard to time of flowering.

4.3.1.2. Effect of mulching on fruit size (cm^2)

The results obtained on fruit size as depicted in Table 14 revealed that there was significant difference among the treatments. The maximum fruit size

Table 14: Effect of different mulching materials on days to flowering, fruit size and fruit weight of Khasi mandarin

Treatments	***Days to flowering***			***Fruit size (cm^2)***			***Fruit weight (g)***		
	2016	***2017***	***Pooled***	***2016***	***2017***	***Pooled***	***2016***	***2017***	***Pooled***
M_0: No mulch	85.50^{ab}	89.00^{ab}	87.25^{ab}	39.89^{c}	40.27^{c}	40.08^{c}	108.40^{c}	110.12^{c}	109.26^{c}
M_1: Rice husk	83.75^{b}	86.58^{b}	85.17^{b}	42.02^{bc}	42.75^{bc}	42.39^{bc}	117.87^{ab}	120.30^{ab}	119.08^{bc}
M_2: Saw dust	86.58^{a}	89.75^{a}	88.17^{a}	43.35^{ab}	43.84^{ab}	43.59^{ab}	116.47^{ab}	118.60^{ab}	117.53^{bc}
M_3: Chopped banana leaves & pseudostem	85.33^{ab}	88.33^{ab}	86.83^{ab}	45.88^{ab}	46.25^{ab}	46.06^{ab}	113.70^{bc}	116.43^{bc}	115.07^{bc}
M_4: FYM	84.25^{b}	86.92^{b}	85.58^{b}	45.87^{ab}	46.46^{ab}	46.17^{ab}	120.17^{ab}	122.57^{ab}	121.37^{ab}
M_5: Forest leaves	86.25^{ab}	89.67^{ab}	87.96^{ab}	45.65^{ab}	45.99^{ab}	45.82^{ab}	121.23^{ab}	123.70^{ab}	122.47^{ab}
M_6: Rice straw	85.25^{ab}	88.33^{ab}	86.79^{a}	42.17^{bc}	42.48^{bc}	42.32^{bc}	118.90^{ab}	121.17^{ab}	120.03^{ab}
M_7: Transparent polythene (100µ)	84.92^{ab}	87.33^{ab}	86.13^{b}	46.82^{ab}	47.12^{ab}	46.97^{ab}	124.87^{ab}	126.60^{ab}	125.73^{ab}
M_8: Black polythene (100µ)	85.25^{ab}	87.25^{ab}	86.25^{b}	48.60^{a}	49.04^{a}	48.82^{a}	125.57^{a}	128.57^{a}	127.07^{a}
SEm±	*0.63*	*0.80*	*0.51*	*1.71*	*1.69*	*1.20*	*3.35*	*3.45*	*2.40*
CD (p=0.05)	*NS*	*NS*	*NS*	*5.08*	*5.02*	*3.45*	*9.94*	*10.26*	*6.90*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance.

Means within columns were separated by Duncan's multiple range test (DMRT).

NS = Non-significant at 5% level of significance.

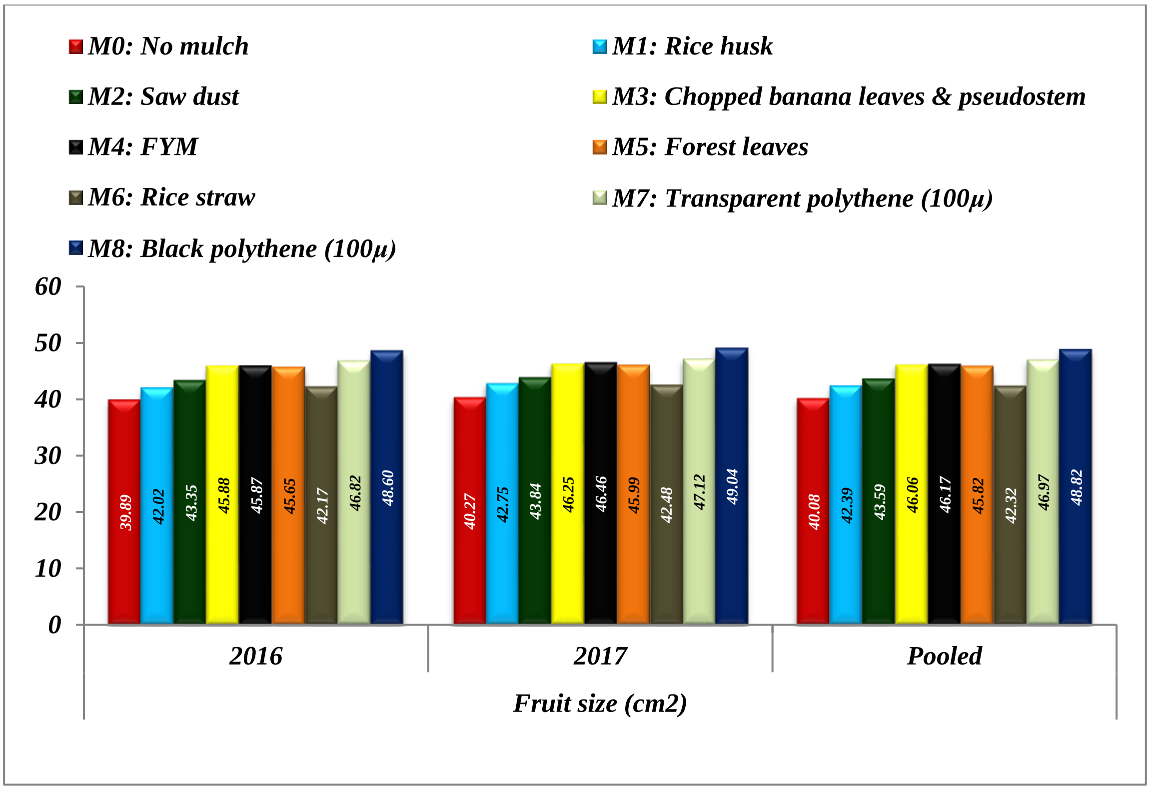

Fig 15: Effect of different mulching materials on fruit size of Khasi mandarin

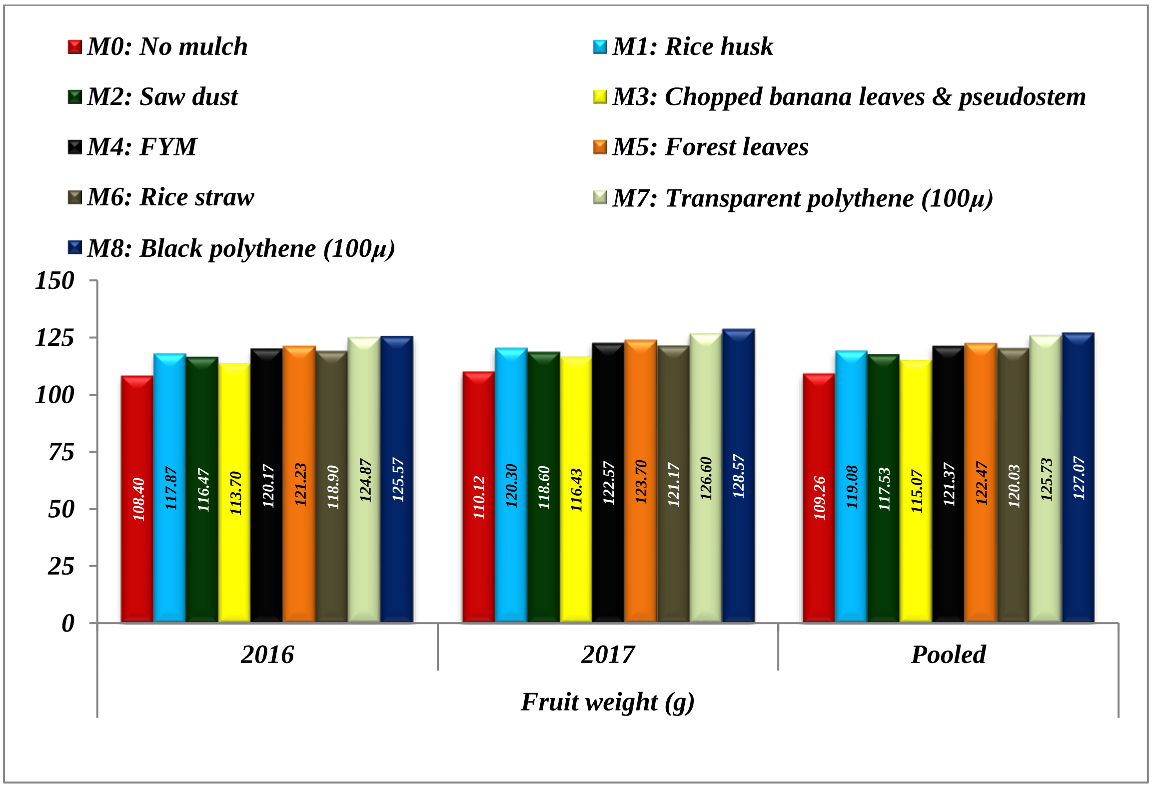

Fig 16: Effect of different mulching materials on fruit weight of Khasi mandarin

was recorded in black polythene (M_8) mulch measuring 48.60 and 49.04 cm^2 followed by the treatment with transparent polythene (M_7) that recorded 46.82 and 47.12 cm^2 in both the years of observation with a mean value of 48.82 and 46.97 cm^2, respectively. The minimum fruit size was recorded under no mulch (M_0) condition with 39.89 and 40.27 cm^2 during 2016 and 2017, respectively with a mean value of 40.08 cm^2. The fruit size in transparent polythene (M_7), forest leaves (M_5), FYM (M_4), chopped banana leaves & pseudostem (M_3) and saw dust (M_2) treatment was at par. Further the fruit size in rice straw (M_6) and rice husk (M_1) treatment was at par and was significantly lower than black polythene (M_8). The fruit size in no mulch (M_0) was significantly lower than rest of the treatments except for the two treatments *i.e.* rice husk (M_1) and rice straw (M_6). From the results obtained it is found that, even in the second experimental year it showed similar trend with insignificant increase in the fruit size.

The fruit size in black polythene, transparent polythene, FYM and chopped banana leaves & pseudostem was 17.90, 14.67, 13.12 and 12.98 % higher as compared to no mulch treatments. The various mulches created a micro-climate condition catering to soil moisture availability in the plant basin, probably resulting in active root growth leading to optimum availability of nutrients and food translocation thus enhancing the physiological changes of the fruit. Under black polythene mulching material, similar findings were recorded by Bakshi *et al*. (2014) in Strawberry *cv.* Chandler with maximum fruit length of 3.93 cm and fruit breadth of 3.16 cm, however, under control the minimum fruit length and breadth was recorded. The results are constant with those of previous reports in which plastic mulch treatment recorded maximum fruit size whereas minimum was observed in control (Gosh and Bera, 2015; Bal and Singh, 2011; Castaneda *et al.*, 2009; Sharma and Khokhar, 2006; Agrawal *et al.*, 2005).

3.1.3. Effect of mulching on fruit weight (g)

The data pertaining to the weight of fruit is represented in Table 14, which indicated that the fruit weight was highest under black polythene (M_8) mulch with 125.57 and 128.57 g during 2016 and 2017, respectively with mean value of 127.07 g, subsequently transparent polythene (M_7) treatment followed with 124.87 and 126.60 g during the experimental years, respectively. The treatment devoid of mulched materials recorded the lowest fruit weight mean value of 109.26 g. The fruit weight recorded in rice husk (M_1), saw dust (M_2), FYM (M_4), forest leaves (M_5), rice straw (M_6) and transparent polythene (M_7) treatment did not differ significantly however it was found to have significant increase over chopped banana leaves & pseudostem (M_3) and no mulch (M_0). Also the fruit weight of black polythene (M_8) treatment was significantly higher than the no mulch (M_0).

The increase in fruit weight could be as a result of better availability of moisture and nutrients, owing to the various mulches used which thereby, improved the soil environment for growth and development of plant, congenial C:N ratio, elevated photosynthates production, thus improving the fruiting characteristics and ultimately increased the weight of the fruit. Few researchers studied and observed that there was a significant increased on the average fruit weight of tomato (Moreno and Moreno, 2008; Hasan *et al.*, 2005) and lettuce (Jenni *et al*., 2003) with plastic mulch. This may be attributed to larger size of fruits produced by the plants provided with black polythene mulch, due to increased fruit weight and also creation of favourable soil temperature for fruit development. The present results are in line with the findings of Bakshi *et al.* (2014) in strawberry *cv*. Chandler, Bal and Singh (2011) in Ber, Singh *et al.* (2010) in Aonla, Maji and Das (2008) in Guava, Ali and Gaur (2007) in strawberry, Mukherjee *et al*. (2004) in Ber, Shirgure *et al*. (2003) in Nagpur mandarin, Gosh and Bauri (2003) in Mango and Singh *et al*. (2002) in Apricot. The improved rind thickness of fruit resulted by mulching treatments maybe due to better availability of moisture and nutrients required, which ultimately improved the internal growth and development of Peach (Yadav *et al.*, 2013).

4.3.1.4. Effect of mulching on fruit yield/ tree (kg)

The experimental results relating to fruit yield per tree revealed that the plants treated with various mulching materials resulted in significantly better fruit yield compared to control (Table 15). Mulching with black polythene (M_8) resulted in maximum yield in both the experimental years with a yield of 31.18 and 32.12 kg, respectively with mean of 31.65 kg/plant and the subsequent highest was obtained from the transparent polythene (M_7) mulch with 30.80 and 31.40 kg during the study period. Among the treatments studied, the lowest fruit yield per tree was recorded under control (M_0) *i.e.* 25.10 and 25.85 kg/plant in both the years, respectively. The fruit yield per tree in black polythene (M_8) and white polythene (M_7) treatment caused a significant increase over the other treatments. The fruit yield per tree in FYM (M_4) and forest leaves (M_5) treatment was at par and was significantly more than rice straw (M_6) treatment. Further the yield per treatment in rice husk (M_1), saw dust (M_2) and chopped banana leaves & pseudostem (M_3) did not differ significantly but established to have significant increase over no mulch (M_0). However, during 2017-18 the fruit yield per tree in FYM (M_4), forest leaves (M_5) and rice straw (M_6) treatment was at par. Addition of black polythene, transparent polythene, FYM and forest leaves caused an increase of 19.53, 18.10, 14.33 and 13.34 % in fruit yield per tree over no mulch treatment.

These finding of higher yield under polythene mulch may be attributed to higher number of flowers and increased fruit set due to increased available water in the root zone of the crop, with less evaporation losses and better weed control. It may also be attributed to comparatively increased soil temperature, proper moisture availability (as influenced by mulches), elevated CO_2 level and respiration rate, proper root growth, better up take of nutrients, and absence of weeds in the field which were responsible for creating favourable microclimate around plants, efficient photosynthates mobilization and utilization thus

Table 15: Effect of different mulching materials on fruit yield per tree and projected yield of Khasi mandarin

Treatments	***Fruit yield per tree (kg)***			***Projected yield (q/ha)***		
	2016	***2017***	***2016***	***2017***	***2016***	***2017***
M_0: No mulch	25.10^{e}	25.85^{d}	25.47^{e}	100.39^{e}	103.39^{d}	101.89^{f}
M_1: Rice husk	27.12^{d}	27.50^{c}	27.31^{d}	108.47^{d}	110.01^{c}	109.24^{e}
M_2: Saw dust	28.05^{cd}	28.23^{c}	28.14^{c}	112.21^{cd}	112.92^{c}	112.57^{cd}
M_3: Chopped banana leaves & pseudostem	27.57^{cd}	27.98^{c}	27.77^{d}	110.27^{cd}	111.92^{c}	111.09^{de}
M_4: FYM	29.67^{b}	29.80^{b}	29.73^{b}	118.67^{b}	119.20^{b}	118.93^{b}
M_5: Forest leaves	29.25^{b}	29.52^{b}	29.39^{b}	117.01^{b}	118.08^{b}	117.55^{b}
M_6: Rice straw	28.17^{c}	29.30^{b}	28.74^{c}	112.67^{c}	117.21^{b}	114.94^{c}
M_7: Transparent polythene (100µ)	30.80^{a}	31.40^{a}	31.10^{a}	123.19^{a}	125.59^{a}	124.39^{a}
M_8: Black polythene (100µ)	31.18^{a}	32.12^{a}	31.65^{a}	124.71^{a}	128.48^{a}	126.59^{a}
SEm±	*0.33*	*0.27*	*0.21*	*1.30*	*1.08*	*0.85*
CD (p=0.05)	*0.97*	*0.80*	*0.61*	*3.86*	*3.22*	*2.43*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance.

Means within columns were separated by Duncan's multiple range test (DMRT).

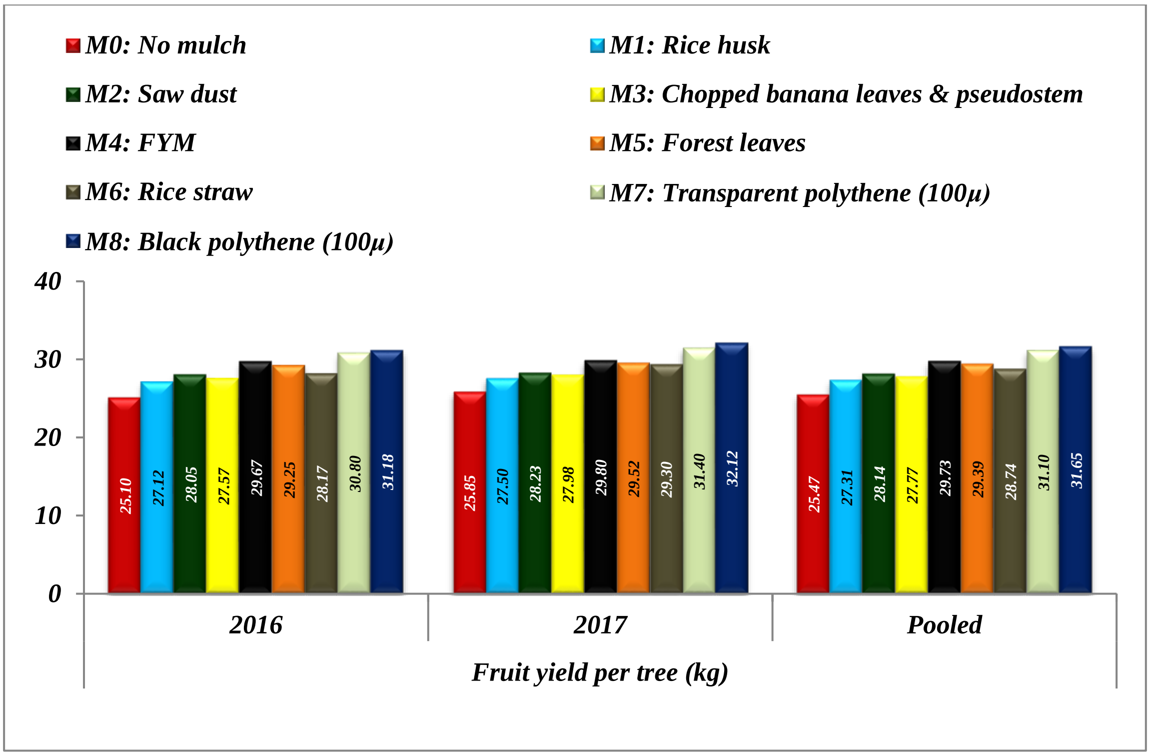

Fig 17: Effect of different mulching materials on fruit yield per tree of Khasi mandarin

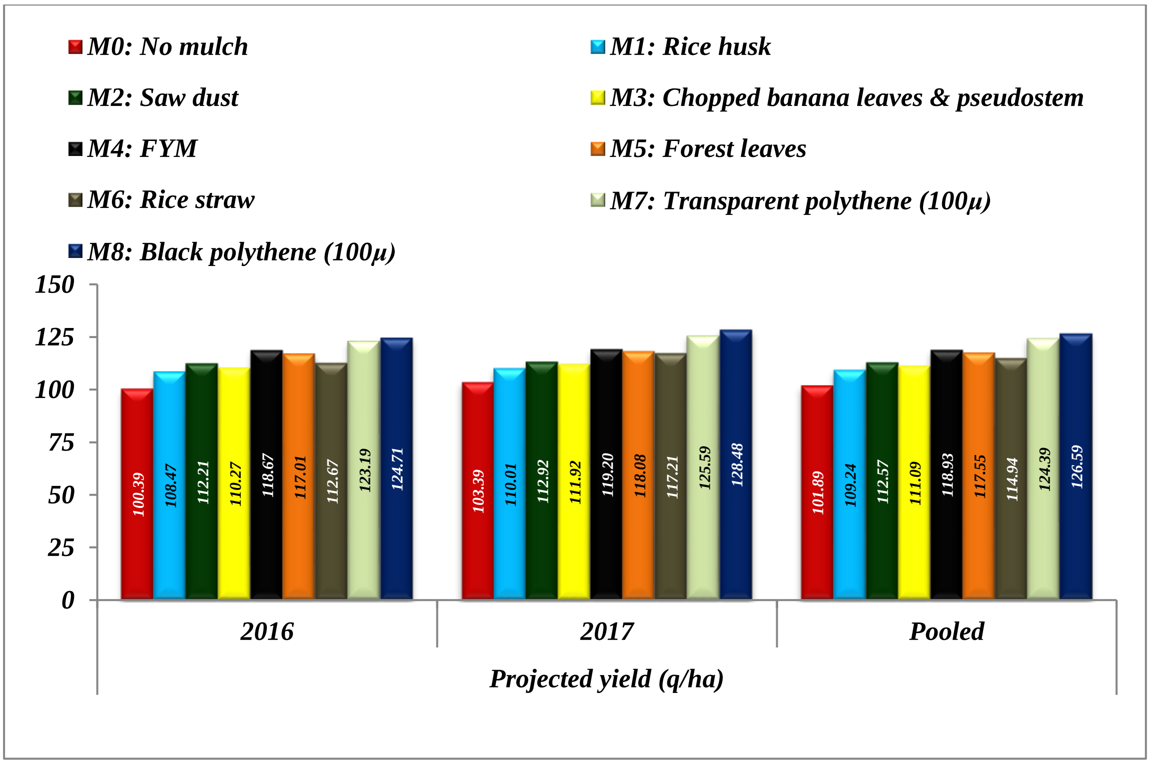

Fig 18: Effect of different mulching materials on projected yield of Khasi mandarin

changing the physiological performance of plant growth and development. Plastic mulches are known to cause chimney effect which results in abundant CO_2 availability for plants which is necessary for photosynthesis leading to added higher plant growth since plastic mulch is nearly impervious to CO_2. Plastic Mulch improved the performance of plant and vegetative development as a result of reduction in leaching of fertilizers, higher nutrient and efficient water uptake. This findings are similar with the reports of Mal *et al*. (2006) who reported increased number of flowers in plants under black polythene mulch in pomegranate *cv*. Ganesh. Bakshi *et al*. (2014) also reported highest number of fruits per plant in black polythene mulch in strawberry *cv*. Chandler. The present findings are also in agreement with the verdicts of Kher *et al*. (2010) in Strawberry *cv*. Chandler, Gosh and Baur (2003) in Mango *cv*. Himsagar, Shirgure *et al*. (2003) in Nagpur mandarin, Patra *et al*. (2004) in Guava *cv*. Sardar and Castaneda *et al*. (2009) on Strawberry, Sharma and Kathiravan (2009) in Plum *cv*. Santa Rosa. In contrast, Kumar *et al.* (2012) from his study on different mulch materials impact, reported that transparent polythene mulch gave significantly higher yield of fruit in Strawberry in comparison to black polythene mulch and the lowest was reported under control.

4.3.1.5. Effect of mulching on projected yield (q/ha)

Data from Table 15 showed that the projected yield (q/ha) were significantly different among various treatments. The average projected yield was recorded highest under black polythene (M_8) mulch (126.59 q/ha), followed by transparent polythene (M_7) mulch (124.39 q/ha) and FYM (M_4) (118.93 q/ha). The treatment with no mulch (M_0) revealed minimum fruit yield per tree with the mean of 101.89 q/ha.

4.3.2. Effect of mulching on quality attributes

The outcome of the various quality parameters of Khasi mandarin *viz*., TSS, titratable acidity, colour, firmness and reducing sugar content as influenced by different organic and inorganic mulches of the harvested fruits are discussed. The quality of fresh fruits and vegetables are generally based on two factors *viz.*, chemical or physical characteristics or a combination of both. Besides high yielding ability of a crop, the other attributes of interest to the customers are visual appearance, texture/firmness, sensory, nutritional and food safety.

4.3.2.1. Effect of mulching on total soluble solids (ºBrix)

Treatment difference in terms of TSS content was noticed within an average range of 10.99 to 11.53 ºBrix during the experimental years. The data is presented in Table 16. Black polythene mulch (M_8) treatment recorded maximum TSS with 11.12 and 11.94 ºBrix during 2016 and 2017 respectively, then the forest leaves (M_5) mulch with values of 10.98 and 11.83 ºBrix in both years of study respectively. The lowest mean TSS content (10.89 ºBrix) was recorded in the treatment no mulch (M_0). The TSS content in saw dust (M_2), chopped banana leaves & pseudo-stem (M_3) and FYM (M_4) treatment was at par but was found to be significantly low compared to black polythene (M_8). The TSS content in forest leaves (M_5), rice straw (M_6) and transparent polythene (M_7) treatment did not differ significantly. Whereas the TSS content in rice husk (M_1) and no mulch (M_0) was at par and established to be significantly lower than rice straw (M_6). In the succeeding year of the experiment, the TSS content recorded in saw dust (M_2) was at par with other treatments apart from chopped banana leaves & pseudostem (M_3), rice husk (M_1) and no mulch (M_0). Increase in TSS is due to, increased soil temperature (25.37 °C) and maximum nutrient uptake (198.01 kg/ha of Nitrogen and 218.67 kg/ha of Potash) under black polythene mulch treatment.

Mulching ensured higher values of soil moisture as a result of reducing water evaporation from the soil surface. The changes occurred in the soil water regime had an obvious effect on fruit quality. Thus, soil maintenance systems by mulching might have a positive influence on the TSS. Bal and Singh (2011) in their study on mulching material effect in Ber recorded that black polythene

Table 16: Effect of different mulching materials on total soluble solids and tritratable acidity of Khasi mandarin

Treatments	*Total soluble solids (°Brix)*			*Titratable acidity (%)*		
	2016	***2017***	***2016***	***2017***	***2016***	***2017***
M_0: No mulch	10.47^{c}	11.32^{c}	10.89^{d}	0.23^{c}	0.26^{c}	0.24^{c}
M_1: Rice husk	10.50^{c}	11.47^{bc}	10.98^{d}	0.27^{bc}	0.30^{bc}	0.28^{bc}
M_2: Saw dust	10.56^{bc}	11.56^{ab}	11.06^{cd}	0.32^{bc}	0.33^{bc}	0.32^{b}
M_3: Chopped banana leaves & pseudostem	10.65^{bc}	11.40^{c}	11.02^{cd}	0.24^{bc}	0.27^{bc}	0.26^{c}
M_4: FYM	10.66^{bc}	11.62^{ab}	11.14^{bcd}	0.30^{bc}	0.33^{bc}	0.31^{bc}
M_5: Forest leaves	10.98^{ab}	11.83^{ab}	11.41^{ab}	0.43^{a}	0.44^{a}	0.43^{a}
M_6: Rice straw	10.66^{b}	11.55^{ab}	11.11^{cd}	0.28^{bc}	0.31^{bc}	0.30^{bc}
M_7: Transparent polythene (100μ)	10.85^{ab}	11.72^{ab}	11.28^{ab}	0.33^{b}	0.36^{b}	0.34^{b}
M_8: Black polythene (100μ)	11.12^{a}	11.94^{a}	11.53^{a}	0.43^{a}	0.45^{a}	0.44^{a}
SEm±	*0.13*	*0.13*	*0.09*	*0.03*	*0.03*	*0.02*
CD (p=0.05)	*0.38*	*0.38*	*0.26*	*0.08*	*0.08*	*0.06*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance.

Means within columns were separated by Duncan's multiple range test (DMRT).

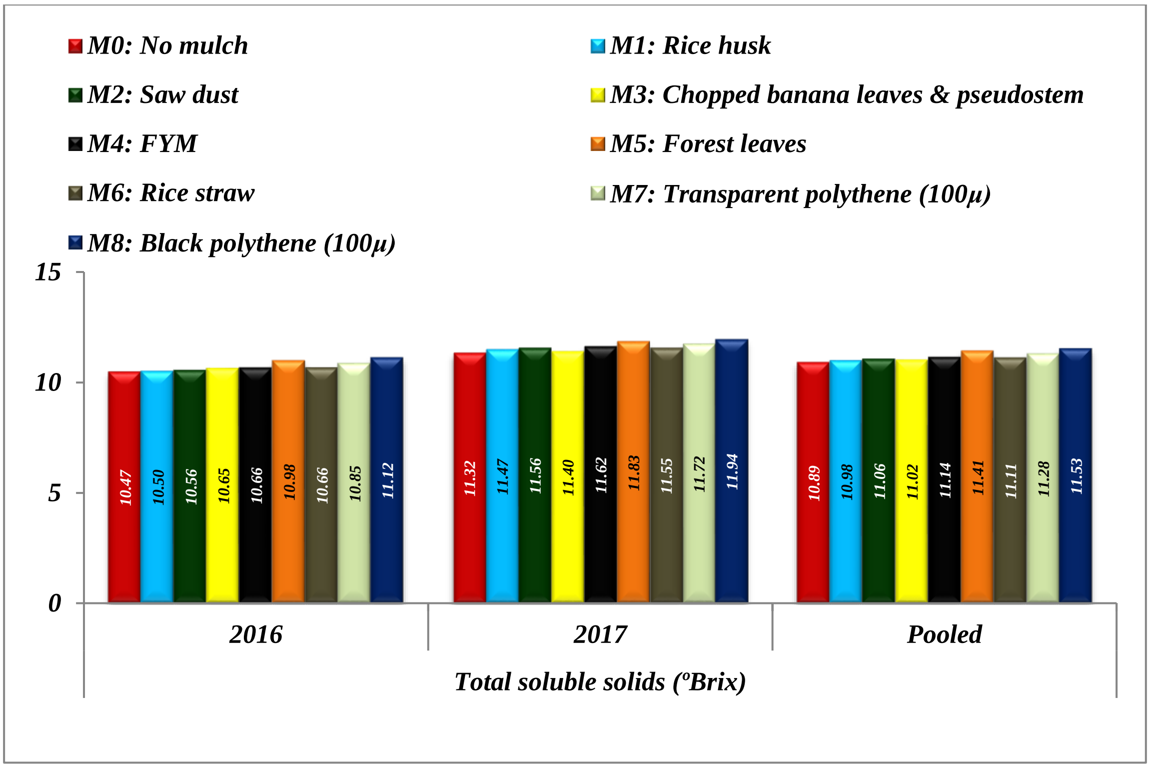

Fig 19: Effect of different mulching materials on Total Soluble Solids of Khasi mandarin

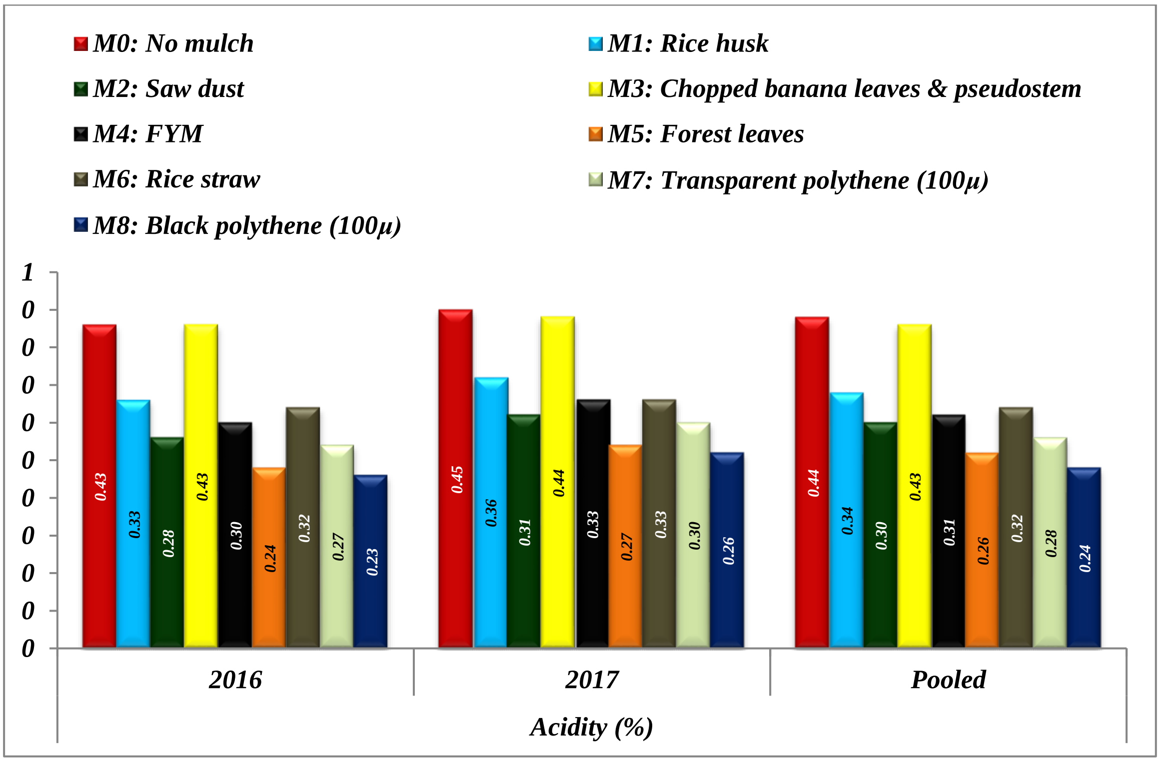

Fig 20: Effect of different mulching materials on titratable acidity of Khasi mandarin

in combination with gramaxone (1 litre per hactare) gave maximum TSS of 12.16 %, and that Paddy straw mulch and Sarkanda recorded higher TSS content in comparison to control. The present observations are consistent with the findings of Kim *et al.* (2008) who reported that applying mulches 2and 3 weeks prior to harvesting recorded higher TSS of 0.3 °Brix than control from his study on growth and fruit quality of Plum (*Prunus domestica* L.) in regard to effect of pre harvest reflective mulch. Similar findings was reported in which black polythene mulch gave better results *viz*., Bakshi *et al*. (2014) in Strawberry, Kaur and Kaundal (2009) in Plum, Sharma and Khokhar (2006) in Strawberry (*Fragaria x ananassa* Duch.) *cv*. Chandler, Pande *et al*. (2005) in Apple *cv*. Red Delicious, Gaikwad *et al*. (2004) in Nagpur mandarin, and Ghosh and Bauri (2003) in Mango.

In contrast, Ghosh *et al*. (2009) reported in Sweet Orange [*Citrus sinensis* (L.) Osbeck] *cv*. Mosambi that juice recovery (59.67 %), TSS (9.90 °Brix), TSS: acid ratio (46.33), total sugars (6.05 %), reducing sugars (3.35 %) were highest in plants treated with dry leaves mulch + basin irrigation at 30 l/plant at 20 days interval. Whereas, acidity (0.28 %), Vitamin-C (78.40 mg/100 ml) was highest in black polythene + basin irrigation at 30 l/Plant at 20 days interval. Manoj *et al*. (2015) reported maximum TSS in Kinnow under paddy straw mulch. Study in Strawberry by Kumar *et al*. (2012) showed higher TSS in organic mulches, and amongst the inorganic mulches, transparent polyethylene resulted in higher TSS in comparison to black polythene. Singh *et al*. (2010) in their study on Aonla *cv*. NA-7 revealed maximum TSS of 8.25 % from paddy straw mulch, subsequently followed by grass mulch (8.15 %) and maize straw mulch (8.10 %) and lowest in control (7.85 %).

4.3.2.2. Effect of mulching on titratable acidity

In the present investigation, the result obtained on titratable acidity percentage revealed varying degree of response in all the mulch tested (Table 16). The effective treatment for highest average acidity content (0.44 %) was reported from no mulch (M_0) mulch in both years of studies, while the treatment black polythene (M_8) recorded lowest acidity content of 0.23 and 0.26 % during 2016 and 2017, respectively. The acidity of the fruit in rice husk (M_1), saw dust (M_2), FYM (M_4), forest leaves (M_5), rice straw (M_6) and transparent polythene (M_7) treatment did not show any significant difference. However, acidity in no mulch (M_0) and chopped banana leaves & pseudostem (M_3) was at par and found to be significantly higher than black polythene (M_8). Also in the subsequent experiment, it showed similar trend with insignificant increase in the acidity. The pooled TSS:TA ratio was recorded lowest in no mulch and highest was found to be in black polythene with a value of 24.75 and 48.04 respectively.

Similar results were recorded from studies in Strawberry *cv*. Chandler conducted by Bakshi *et al*. (2014) showed that acidity was highest (0.80 %) under control whereas, black polythene mulch gave the lowest (0.64 %). Similar results were reported in Strawberry *cv*. Oso Grande by Hassan *et al*. (2000) on the yield and quality as affected by different mulches and observed that fruits under black polythene mulch gave minimum acid content (1.13 %) and control resulted in maximum (1.33 %).

On the contrary, higher organic acids content from plastic mulch were reported by Melgarejo *et al*. (2012) in Plum. Kumar *et al*. (2012) in Strawberry reported that transparent polyethylene mulch showed significantly higher fruit acidity followed by black polyethylene whereas, control treatment recorded the lowest fruit acidity. Studies in Apple *cv*. Red Delicious by Pande *et al*. (2005) documented that titratable acidity was highest under dry grass mulch (0.25 %) followed by black polyethylene (0.20 %) and minimum under clean cultivation (0.19 %) treatments.

However, in another investigation in Nagpur mandarin by Gaikwad *et al*. (2004), no significant impact on the fruit acidity was recorded as a result of using various mulches. Similar conclusion that different mulching treatments did not influence the fruit acidity was given for Mango by Ghosh and Bauri (2003).

4.3.2.3. Effect of mulching on colour of fruit

The colour of the fruits did not show significant difference with respect to application of different mulching materials in both the years **(**Table17**)**. The maximum rating was recorded under black polythene (M_8) mulch with 4.17 and 4.00 and mean of 4.08 during 2016 and 2017 respectively and the minimum was recorded under no mulch (M_0) with a rating of 3.17 and 3.08 and mean of 3.13, respectively during 2016 and 2017.

4.3.2.4. Effect of mulching on firmness

The results obtained by Hedonic scale method on the firmness of harvest fruits borne under different mulched treatments have been presented in Table 17. It was apparent from the data that, the fruits harvested from rice husk (M_1) mulch was firmest with an average value of 4.29, then 3.71 and 3.13 was recorded in treatments of no mulch (M_0) and saw dust (M_2) mulch respectively. Fruits harvested from Khasi mandarin grown under rice straw mulch recorded the softest with mean value of 2.13. The firmness of the fruit in rice husk (M_1) and no mulch (M_0) treatment was at par and showed significant increase over rice straw (M_6). The firmness of the fruit in chopped banana leaves & pseudostem (M_3), FYM (M_4), forest leaves (M_5), transparent polythene (M_7) and black polythene (M_8) treatment did not show any significant difference. Further, fruit firmness in saw dust (M_2) was significantly higher than rice straw (M_6) treatment.

The firmness and maintenance of structure and function of cell wall, leading to enhanced shelf life and also controlled disintegration of mitochondria and endoplasmic reticulum might be due to effect of mulching since it results in many of the chemical and physical effects that occur during ripening of fruits which are attributed to enzyme action. Softening of fruits during storage is closely associated with an increase in pectin esterase and polygalacturonate

Table 17: Effect of different mulching materials on days fruit colour, firmness and reducing sugar of Khasi mandarin

Treatments	***Fruit colour***			***Firmness***			***Reducing sugar (%)***		
	2016	***2017***	***Pooled***	***2016***	***2017***	***Pooled***	***2016***	***2017***	***Pooled***
M_0: No mulch	3.17^{b}	3.08^{b}	3.13^{b}	3.75^{ab}	3.67^{ab}	3.71^{b}	6.78^{c}	6.68^{b}	6.73^{d}
M_1: Rice husk	3.92^{ab}	3.83^{a}	3.88^{a}	4.17^{a}	4.42^{a}	4.29^{a}	7.19^{bc}	7.39^{ab}	7.29^{cd}
M_2: Saw dust	3.83^{ab}	3.67^{ab}	3.75^{a}	3.17^{bc}	3.08^{bc}	3.13^{c}	8.03^{ab}	8.21^{a}	8.12^{ab}
M_3: Chopped banana leaves & pseudostem	3.67^{ab}	3.92^{a}	3.79^{a}	2.75^{cd}	2.83^{bc}	2.79^{cd}	7.48^{abc}	7.59^{a}	7.54^{bc}
M_4: FYM	3.83^{ab}	3.75^{a}	3.79^{a}	2.50^{cd}	2.42^{c}	2.46^{d}	7.75^{ab}	7.79^{a}	7.77^{ab}
M_5: Forest leaves	3.67^{ab}	3.58^{ab}	3.63^{ab}	2.67^{cd}	2.83^{bc}	2.75^{cd}	7.80^{ab}	8.06^{a}	7.93^{ab}
M_6: Rice straw	3.75^{ab}	3.75^{a}	3.75^{a}	2.17^{d}	2.08^{c}	2.13^{d}	7.39^{bc}	7.30^{ab}	7.35^{bc}
M_7: Transparent polythene (100μ)	4.00^{ab}	3.83^{a}	3.92^{a}	2.50^{cd}	2.58^{bc}	2.54^{cd}	7.96^{ab}	8.18^{a}	8.07^{ab}
M_8: Black polythene (100μ)	4.17^{a}	4.00^{a}	4.08^{a}	2.67^{cd}	2.75^{bc}	2.71^{cd}	8.19^{a}	8.23^{a}	8.21^{a}
SEm±	*0.29*	*0.20*	*0.18*	*0.25*	*0.27*	*0.18*	*0.26*	*0.28*	*0.19*
CD (p=0.05)	*NS*	*NS*	*NS*	*0.75*	*0.80*	*0.53*	*0.78*	*0.83*	*0.55*

Note: Different small letters within the columns after mean values indicate significant differences among treatments at 5% level of significance.

Means within columns were separated by Duncan's multiple range test (DMRT).

NS = Non-significant at 5% level of significance.

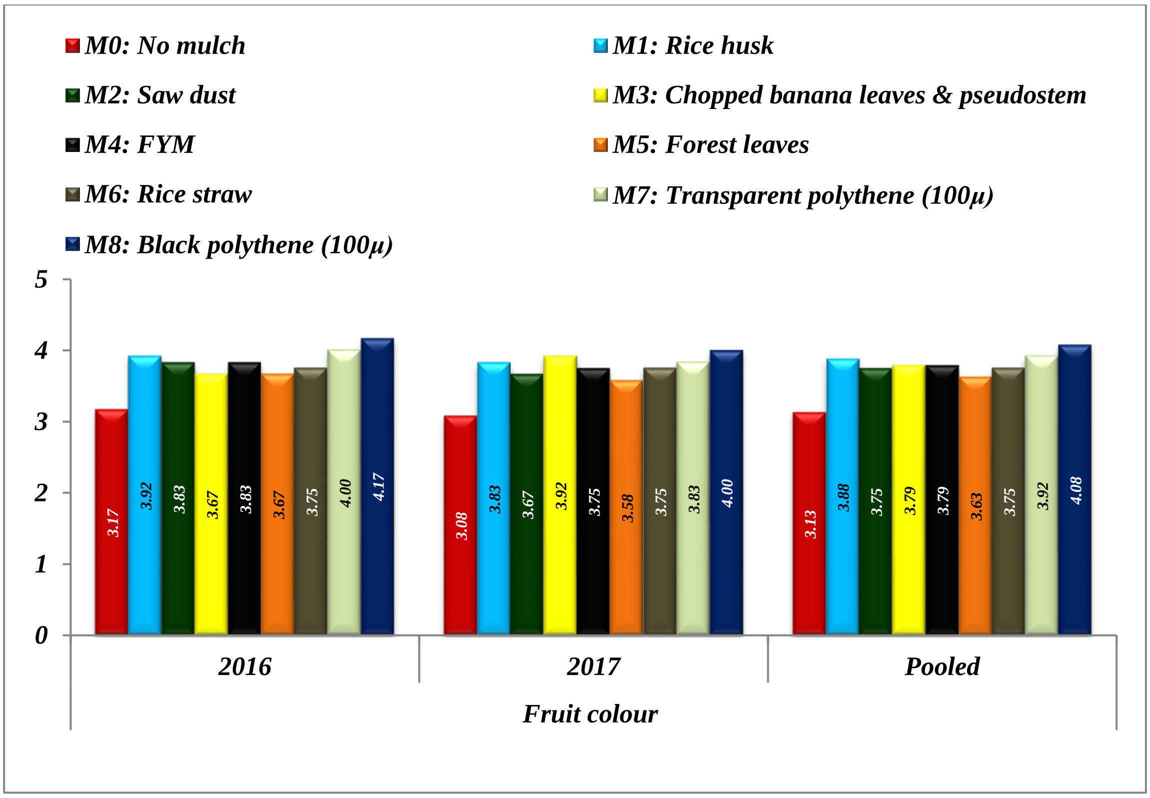

Fig 21: Effect of different mulching materials on fruit color of Khasi mandarin

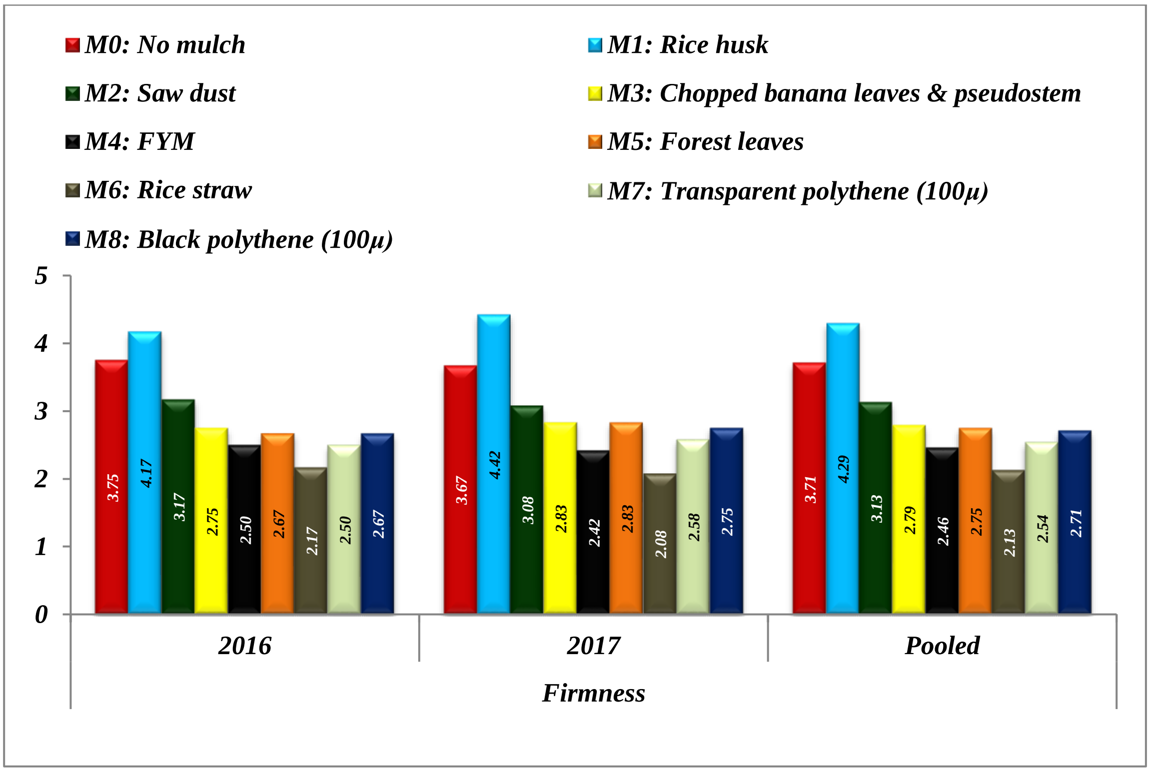

Fig 22: Effect of different mulching materials on firmness of Khasi mandarin

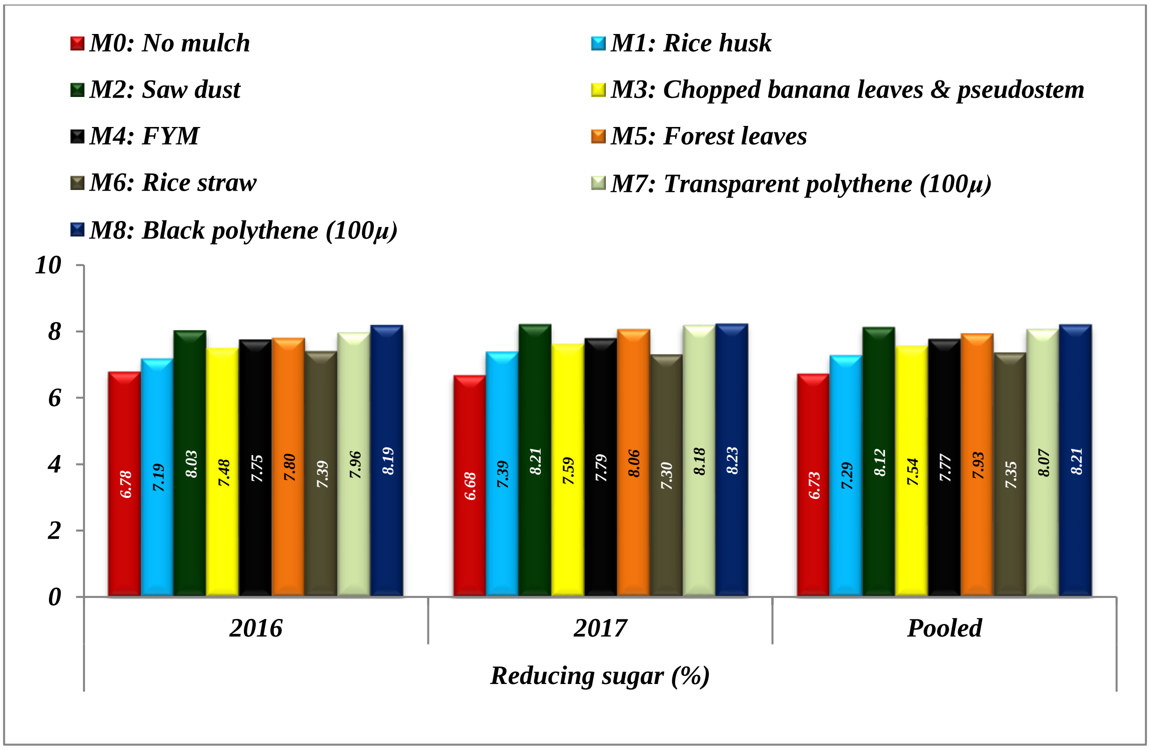

Fig 23: Effect of different mulching materials on reducing sugar of Khasi mandarin

activities as reported by Bakshi *et al*. (2014) in Strawberry. Similar finding by Lang *et al*. (2001) reported that mulching the plants helps in better uptake of calcium by the Apple tree which will be reflected in storage potential of the fruit.

4.3.2.5. Effect of mulching on reducing sugar

In the present investigation, the results obtained on reducing sugar percentage revealed varying degree of response in all the mulch tested. It was clear from the results presented in Table 17 that black polythene (M_8) mulch resulted in highest reducing sugar content with values of 8.19 and 8.23 % during 2016 and 2017, respectively. The mulch treatments of saw dust (M_2) and transparent polythene (M_7) closely followed with mean values of 8.12 and 8.07 %, respectively. The lowest was recorded in treatments without any mulch materials (M_0) reporting 6.78 and 6.68 % during 2016 and 2017, respectively. The reducing sugar of the fruit in saw dust (M_2), FYM (M_4), forest leaves (M_5), transparent polythene (M_7) treatment was at par and showed significant increase over no mulch (M_0). The reducing sugar of the fruit in rice husk (M_1) was significantly higher than the black polythene (M_8) treatment. While, chopped banana leaves & pseudostem (M_3) treatment did not show any significant difference with the other treatments. However, during the 2017-18 experiment the reducing sugar of the fruit in rice husk (M_1) did not show any significant difference over black polythene (M_8) treatment.

The data revealed that addition of black polythene, saw dust, transparent polythene and forest leaves caused an increase of 18.03, 17.12, 16.60 and 15.13% reducing sugar over no mulched treatment, respectively. The present findings are in line with Patil (2011) who recorded that paddy straw mulch gave higher total sugar (6.21%), whereas black polythene mulch showed higher reducing sugar (5.38%) and paddy straw mulch resulted in higher non reducing sugar (1.22%). Gosh and Bera (2015) and Mahmoud and Sheren (2014) also recorded the higher sugar acid ratio in plants mulched with black polythene in pomegranate. Similar conclusions were also documented by Sharma and Khokhar, 2006; Pande *et al*., 2005; that black polythene mulch results in higher reducing sugar.

To attain acceptable fruit flavours, sugar plays an important role to create a balanced sugar to acid ratio, wholesome texture and appealing colour development. Higher reducing sugar content under black polythene mulch might be due to high TSS and greater utilization and assimilation of carbohydrates favoured by better hydrothermal regime of soil and higher absorption of nutrients, conservation of soil moisture, regulated temperature and suppression in weed growth. Studies in strawberry conducted by Singh *et al*. (2006) revealed that the environmental conditions during flowering, fruit set and fruit development may also be influenced by mulching treatments which enhanced the sugar content and the fruit yield. The physical soil conditions like temperature and moisture may have been influenced by the mulched treatments which ultimately improved the uptake of nutrients.

On the contrary, investigations by Kumar *et al*. (2012) in Strawberry recorded that total sugars were higher under transparent polyethylene mulching followed by black polyethylene mulch. In a study for comparison for effect of different mulches in Guava *cv*. L-49, Das *et al*. (2010) reported that paddy straw mulch recorded the highest total sugar (6.53 %), reducing sugar (3.80 %) and non-reducing sugar (2.72 %).

4.4. Benefit Cost ratio of various mulching materials

The perusal of the data reported that, in the first year of experiment highest Benefit Cost Ratio was found in FYM (M_4) mulch with a ratio of 1:2.13 and the lowest Benefit Cost Ratio was calculated from black polythene (M_8) mulch and no mulch (M_4) with a ratio of 1:1.91. It is apparent from the table that during 2017, the benefit cost ratio was highest in treatment FYM (M_4) mulch and forest leaves (M_5) mulch with a ratio 1:2.10, while the lowest BCR

Table 18: ***DETAILS OF COSTING FOR BCR (Benefit Cost Ratio) CALCULATION:*** **Common cost (cc)/ treatment**

Sl. No.	***Particulars***	***2016 (Rs)***	***2017 (Rs)***
1.	Labour charges: a. Weeding, fertilizer application, Bordeaux paste application, pesticides application etc	5333.33	6666.66
	b. Irrigation	450.00	600.00
	c. Harvesting	444.44	694.44
2.	Cost of fertilizers	896.40	943.20
3.	Transportation	722.22	788.88
	Total	7846.39	9693.18

Table 19: BCR (Benefit Cost Ratio) of Khasi mandarin (2016)

Treatments	***1***	***2***	***3***	***4***	***5***
	Cost of mulching materials (Rs)	***Yield***	***Sale proceeds at market/ Treatment***	***Total cost till market(col.1 +cc)***	***BCR (col.3/4)***
M_0	0.00	301.20	24096.00	7846.39	3.07
M_1	450.00	325.44	26035.20	8296.39	3.14
M_2	600.00	336.60	26928.00	8446.39	3.19
M_3	300.00	330.84	26467.20	8146.39	3.25
M_4	500.00	356.04	28483.20	8346.39	3.41
M_5	400.00	351.00	28080.00	8246.39	3.40
M_6	300.00	338.04	27043.20	8146.39	3.32
M_7	1200.00	369.60	29568.00	9046.39	3.27
M_8	1920.00	374.16	29932.80	9766.39	3.06

Table 20: BCR (Benefit Cost Ratio) of Khasi mandarin (2017)

Treatments	*1*	*2*	*3*	*4*	*5*
	Cost of mulching materials (Rs)	*Yield*	*Sale proceeds at market/ Treatment*	*Total cost till market(col.1 +cc)*	*BCR (col.3/4)*
M_0	0.00	310.20	27918.00	9693.18	2.88
M_1	500.00	330.00	29700.00	10193.18	2.91
M_2	700.00	338.76	30488.40	10393.18	2.93
M_3	300.00	335.76	30218.40	9993.18	3.02
M_4	500.00	357.60	32184.00	10193.18	3.16
M_5	400.00	354.24	31881.60	10093.18	3.15
M_6	500.00	351.60	31644.00	10193.18	3.10
M_7	1280.00	376.80	33912.00	10973.18	3.09
M_8	1950.00	385.44	34689.60	11643.18	2.98

Cost Ratio was worked out by taking into account the cost of treatment and selling the fruits at the rate of Rs 50 and Rs 60/kg in 2016 and 2017 respectively. The highest benefit cost ratio in FYM (M_4) and forest leaves (M_5) is due to the lower cost of the mulching material even though the yield is higher in black and white polythene mulch. In comparison to the organic mulch, results documented from inorganic mulches showed higher yield however, relatively higher BCR was recorded from organic mulches and it is recommended to use the organic materials as mulches in farmer's field since they are readily available at lower cost. Kumar *et al*. (2014) corroborated that, the highest net income was obtained from the organic mulch and also gave an additional income as compared to control. Singh *et al*. (2014) studied on use of organic mulches for organic Ginger cultivation where it was documented that the yield and net return was higher from oak leaves used as bio-mulch in comparison to control.

CHAPTER V

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

The present investigation entitled, **"Effect of mulching on soil water conservation and performance of Khasi mandarin (*Citrus reticulata* Blanco) in mid-hill regions of Mokokchung District of Nagaland"** was carried out in the farmer's field of Chuchuyimlang Village of Mokokchung District of Nagaland, during the year 2016 to 2018. The analysis of the soil parameters and harvested fruits were done in the Laboratory of Department of Soil and Water Conservation, SASRD, Medziphema Campus, Nagaland University, Medziphema under Dimapur District.

The salient findings thus obtained from the study are summarized below:

Objective I: To study the effect of mulching on soil water dynamics, soil temperature and soil properties

1. Black and transparent polythene mulching was significantly better in moisture retention in comparison to the rest of treatments but with the exception to FYM in some observations the moisture content was statistically at par. We also could conclude that organic mulches M_1 to M_6 resulted in similar moisture content in soil but significantly higher when compared to no mulch plots.
2. Mulching kept all the mulched plots maintained a relatively higher soil temperature than the control plots and maintained a favorable temperature for the root.
3. Significantly higher bulk density was observed under no mulch (M_0) followed by black polythene (M_8) mulch and minimum in the saw dust (M_2) mulch treatment in both the years.
4. The particle density after mulching did not show any variation after two years of treatment with various organic and inorganic mulching materials and the results were found to be insignificant.
5. Maximum water holding capacity (WHC) was significantly higher in

black polythene (M_8) mulch and minimum in no mulch (M_0) in both the years. The maximum WHC recorded in the second year of experiment further increased in all the treatments.

6. The percent aggregates > 0.25 mm of the soil was recorded highest in FYM (M_4) mulch in both the years of the experiment. Followed by saw dust (M_2) and the lowest percent aggregates > 0.25 mm was found in no mulch (M_0)
7. The soil pH showed that there was variation during the two years of investigation. In the first experimental year the data was found to be non-significant however in the following year the data recorded showed that significant decrease from the no mulch (M_0).
8. Soil organic carbon recorded significantly highest value in treatment FYM (M_4) mulch and minimum in devoid of mulch (M_0) materials.
9. Significantly highest available nitrogen was found to be in the treatment FYM (M_4) followed by forest leaves (M_5) and the least in no mulch (M_0) in both the years.
10. Available phosphorus increased significantly in the FYM (M_4) mulch and the second highest was recorded in rice husk (M_1) mulch and the minimum in no mulch (M_0) treatment in both the years.
11. Treatment FYM (M_4) mulch revealed the highest available potassium which was followed by rice straw (M_6) mulch and the lowest was found in treatment devoid of mulch.

Objective II: To evaluate the effect of different mulching materials on yield and yield attributes

The outcome of the various yield parameters *viz.*, days to flowering, fruit size (cm^2), fruit weight (g), fruit yield/ tree (kg), projected yield (q/ha) and quality parameters *viz.*, TSS (°Brix), titratable acidity, colour, firmness and reducing sugar content as influenced by different organic and inorganic mulches during the crop growth and harvest are summarized.

1. Size of fruits was significantly higher in black polythene (M_8) mulch and followed by the treatment with transparent polythene (M_7) and the minimum in no mulch (M_0) in both the years of investigation.
2. The data pertaining to the weight of fruit were significantly influenced by various treatments in the experimental years. The treatment black polythene (M_8) mulch and transparent polythene (M_7) showed higher values, while no mulch (M_0) showed lower values in this parameter.
3. Parameter like fruit yield per tree was statistically maximum in black polythene (M_8) treatment and lowest under control (M_0).
4. The average projected yield was recorded highest under black polythene (M_8) mulch, followed by transparent polythene (M_7) mulch and the minimum in no mulch (M_0).
5. Total soluble solids (TSS) content recorded significantly highest value in treatment M_8 (black polythene mulch), followed by M_5 (forest leaves) and minimum in no mulch (M_0) during the experimental years.
6. Significantly higher titratable acidity percentage was recorded in no mulch (M_0) treatment in both years of study, while the treatment black polythene (M_8) mulch recorded lowest acidity content.
7. Firmness of harvested fruits borne under different mulched treatments and assessed by Hedonic scale method recorded the firmest under rice husk (M_1) mulch followed by no mulch (M_0), then saw dust (M_2) mulch and the softest under rice straw (M_6) mulch in both the years of investigation.
8. Reducing sugar content was significantly influenced by different treatments in both the years of observation. The highest value of reducing sugar was noted in black polythene (M_8) mulch, closely followed by saw dust (M_2) and transparent polythene (M_7) and the lowest was recorded in treatments without any mulch materials (M_0).

Objective III: Benefit Cost ratio of various mulching materials

The highest Benefit Cost Ratio was calculated to be highest in FYM (M_4) and forest leaves (M_5) and lowest in black polythene (M_8) mulch and no mulch (M_0).

CONCLUSIONS

The result established that black polythene mulch (M_8) had the maximum soil moisture conservation and maintained a favorable temperature. The important soil physico-chemical properties like available nutrients, organic carbon and percent aggregates > 0.25 mm were observed to be highest under FYM mulch. In terms of qualitative parameters, black polythene mulch (M_8) gave better content of TSS, reducing sugar, titratable acidity and fruit color and even the yield attributes like fruit size, fruit weight and fruit yield was better in black polythene mulch (M_8) however, the highest BCR was calculated from FYM (M_4) and forest mulch (M_5). Therefore, considering the soil improvement characteristics, yield potentials and benefit cost ratio of various treatments tested and depending on the availability of various mulching materials, it would be appropriate and logical suggestion to conclude that using black polythene or any other organic mulching material can be considered as a better option for adoption by the farming community.

CHAPTER VI

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REFERENCES

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