EFFECTS OF ORGANIC AND INORGANIC MULCHING ON WEEDS, DISEASES, GROWTH AND YIELD OF TOMATO (*Solanum lycopersicum* L) IN BUNGOMA COUNTY, KENYA.

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF MASTER OF SCIENCE (AGRONOMY) IN THE SCHOOL OF AGRICULTURE AND ENTERPRISE DEVELOPMENT OF KENYATTA UNIVERSITY

OCTOBER, 2020
DECLARATION

This thesis is my original work and has not been presented for an award of a degree or any other award at Kenyatta University or any other university.

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DEDICATION

This work is dedicated to my late father Peter Waluchwati Musito
ACKNOWLEDGEMENT

With the innermost gratitude, I acknowledge the help, precious guidance, motivation and dedication of my supervisors, Dr. Joseph Onyango Gweyi, the late Dr. George Kariuki and Dr. Samita Namikoye without which this study would not be complete.

It is my sincere gratitude to thank the chairman and all staff from the Department of Agricultural Science and technology, Kenyatta University, for their generous support and guidance throughout my entire Master of Science in Agronomy course. I indeed appreciate my colleagues, Master of Science in agronomy class, of 2013, Kenyatta University, who advised and cheered me up in the course of this study. My gratitude goes to the Principal and staff of Mabanga agricultural training Centre for accepting to host my experiment on the demonstration farm. I am incredibly grateful to friends and colleagues in the Civil Service for their encouragement and support.

Finally, I am greatly indebted to my wife Nancy, children Providence, Wesley, Emmanuel and Levi, my mother Margaret for their Sacrifice, encouragement and prayers.
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### ABBREVIATIONS AND ACRONYMS

<table>
<thead>
<tr>
<th>Abbr.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASDS:</td>
<td>Agricultural Sector Development strategy</td>
</tr>
<tr>
<td>ATC:</td>
<td>Agricultural training Centre</td>
</tr>
<tr>
<td>BER:</td>
<td>Blossom End Rot</td>
</tr>
<tr>
<td>CABI:</td>
<td>Centre for Agriculture and Bioscience International</td>
</tr>
<tr>
<td>CGB:</td>
<td>County Government of Bungoma</td>
</tr>
<tr>
<td>CAN:</td>
<td>Calcium Ammonium Nitrate</td>
</tr>
<tr>
<td>CDA:</td>
<td>County Director of Agriculture</td>
</tr>
<tr>
<td>CIDP:</td>
<td>County Integrated Development Plan</td>
</tr>
<tr>
<td>DAP:</td>
<td>Di Ammonium Phosphate</td>
</tr>
<tr>
<td>DAS:</td>
<td>Days after Seeding</td>
</tr>
<tr>
<td>DAT:</td>
<td>Days after Transplanting</td>
</tr>
<tr>
<td>DIF:</td>
<td>Day and night Differential</td>
</tr>
<tr>
<td>FAO:</td>
<td>Food and Agriculture Organization</td>
</tr>
<tr>
<td>FAOSTAT:</td>
<td>Food Agricultural Organization Statistics</td>
</tr>
<tr>
<td>GDP:</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GOK:</td>
<td>Government of Kenya</td>
</tr>
<tr>
<td>HCD:</td>
<td>Horticulture crops directorate</td>
</tr>
<tr>
<td>HCDA:</td>
<td>Horticultural Crops Development Authority</td>
</tr>
<tr>
<td>LSD:</td>
<td>Least Significant Difference</td>
</tr>
<tr>
<td>MOA:</td>
<td>Ministry of Agriculture</td>
</tr>
<tr>
<td>MOALFIC:</td>
<td>Ministry of agriculture livestock fisheries irrigation and cooperatives</td>
</tr>
<tr>
<td>RCBHD:</td>
<td>Randomized Complete Block Design</td>
</tr>
<tr>
<td>SRA:</td>
<td>Strategy for Revitalization of Agriculture</td>
</tr>
<tr>
<td>SPAD:</td>
<td>Soil–Plant analysis development</td>
</tr>
<tr>
<td>TSP:</td>
<td>Triple Super Phosphate</td>
</tr>
<tr>
<td>TTYLCV:</td>
<td>Tomato Yellow Leaf Curl Virus</td>
</tr>
<tr>
<td>TSWV:</td>
<td>Tomato spotted wilt virus</td>
</tr>
<tr>
<td>USA:</td>
<td>United States of America</td>
</tr>
<tr>
<td>WAP:</td>
<td>Weeks after planting</td>
</tr>
<tr>
<td>WAT:</td>
<td>Weeks after Transplanting</td>
</tr>
</tbody>
</table>
ABSTRACT

Tomato (*Solanum lycopersicon*) is a major commercial vegetable for small holder farmers in Kenya. Optimizing tomato production provides an opportunity to increase household incomes, improve standards of living and creating employment opportunities for small holder farmers in the tomato growing counties. Despite the favorable climatic conditions, tomato yields in tomato producing Counties remain far below the potential yields range in open field production of 40 to 100 tons per hectare. Low tomato yield is caused by poor soil moisture and fertility management and prevalence of pests and diseases. This study was carried out to evaluate the effects of organic and inorganic mulching on weeds infestations, disease incidences, physiological disorders, growth and yield of tomato varieties. The field experiment was laid out in a Randomized Complete Block Design (RCBD) in split-plot arrangement replicated three times. Two tomato varieties i.e. Cal J (Determinate) and Tylka F1 (Semi indeterminate) were the main plot treatment while the sub plot treatments were composed of black polyethylene film mulch (standard management practice), white polyethylene film mulch (standard management practice), sugarcane Trash at 3kg per meter square and No mulch. Data was collected on plant height, shoot weight, stem thickness, number of branches, number of trusses, number of open flowers , fruit sizes (small, medium and large), Fruit weight (marketable and non-marketable), Soil moisture content, Bacterial wilt and blossom end rot incidence and severity levels and weeds dry weight. The data was subjected to the analysis of variance using SAS software at P≤0.05 and mean separation where significant differences were observed was done using Fischer’s Protected LSD. The mulching treatments showed significant influence on the soil moisture content for both seasons with the highest recorded under the black polythene mulch with a maximum of 22.1% recorded at 8 weeks after transplanting and 18.9% at 6 weeks after transplanting during the first and second seasons respectively. The lowest moisture content was recorded in plots that were not mulched. Mulching with organic and inorganic materials significantly influenced the growth and yield parameters for both seasons in the two tomato varieties. White polyethylene mulch contributed to the highest number of branches per plant (10) and number of flower clusters (30) in Cal-J variety. The tallest plants were recorded in the same treatment on Tylka variety at 143.7 cm while the shortest plants were recorded in the control treatment of Cal J variety. The highest number of large fruits (27) was observed on the white polyethylene mulch of Cal-J variety which was not significantly different from Tylka F1 with the same mulching treatment with (25) fruits per plant during the first season. Tylka F1 under the white polyethylene mulch had the highest yield with 76.8 tonnes per hectare and Cal-J had 71.6 tonnes per hectare under the same mulch treatment recorded during the first season. The lowest tomato yield was observed where no mulch was applied in both seasons under both tomato varieties. The mulching treatments did not have significant influence on the incidences of bacterial wilt and blossom end rot in the two varieties for both seasons. The black polyethylene mulch had the highest weed suppression rate with the control showing the highest fresh and dry weed weight for both seasons. Results from this study shows that inorganic and organic mulch has the potential to increase growth and yield of tomato and suppress weeds growth.
CHAPTER ONE: INTRODUCTION

1.1 Background to the study
Agriculture is the mainstay of the Kenyan economy directly contributing 26 per cent of the GDP annually, and another 25 per cent indirectly. The sector accounts for 65 per cent of Kenya’s total exports and provides more than 70 per cent of informal employment in the rural areas (GoK, 2010). Vision 2030 identified the agriculture sector as one of the key drivers of the economy in order to sustainably achieve average economic growth rate of 10 percent, reduce poverty levels to 25 percent and boost food security to 30 percent by the year 2030 (GoK, 2007; GoK, 2013). To achieve 10 per cent annual economic growth rate smallholder agricultural production accounting for 75% of the total agricultural output should be transformed from subsistence to an innovative, commercially oriented and modern agriculture. This transformation will be accomplished through increasing productivity of crops and improving market access through better value chain management (GoK, 2010).

Tomato is the second most important and widely consumed exotic vegetable accounting for 20% by value of the exotic vegetables. Tomato is cultivated on 18,378 Ha producing 330679 metric tons with average production of 21 metric tons per hectare. (HCD, 2017). Bungoma County is the 3rd largest producer of tomato in the country cultivating 1,055 hectares producing 25,429 tons accounting for 7% by value of the country tomato production with an average production of 24 tons per hectare. (HCD, 2017). Productivity levels for many crops in the country are below potential and for some crop yield over a 5-year period have either remained constant or are on the decline. The stagnation and decline are caused by Low absorption of
modern technology and high levels of waste due to pre- and post-harvest losses (GoK, 2010).

Key production challenges for tomato crop include pests and disease (Heuvelink, 2005; Gatahi, 2020) The major insect pests attacking the crop include; whiteflies, nematodes, spider mites, thrips, Leaf miners, African bollworm and aphids (Anonymous, 2015; Ochilo et al., 2019) Physiological disorders such as nutrient deficiencies, water logging and drought can also affect the crop causing significant losses in quality and quantity. The crop is also affected by calcium deficiency that causes blossom end rot disease on fruits (Heuvelink, 2005). Diseases remain the biggest challenge in tomato production. It is estimated that there are more than 200 known diseases affecting tomatoes (Csizinszky, 2005). Tomato diseases are rampant in lowlands, highlands, tropics and can cause 15-95% crop loss (Csizinszky, 2005); Kenya included; early and late blight, Fusarium wilt, yellow leaf curl virus, tobacco mosaic virus, powdery mildew and bacterial spot (Waiganjo et al., 2006; Mwangi et al., 2020a). However, there is huge potential to increase productivity through adoption of intensive cultural practices such as mulching, fertigation, hydroponics, increased plant densities, promoting multiple stems, intercropping, leaf and stem pruning among others. Control and optimization of environmental factors such as carbon dioxide, temperature, humidity and light in addition to extending the cultivation period is also critical (Heuvelink, 2005).

Mulching plays a critical role in the restoration of soil health, addition of plant nutrient, improvement of the microbial population and increase of organic carbon content (Olaf, 2002; Akhtar et al., 2019). Mulches affect the plant microclimate,
modifying the energy balance of the environment and decreasing the soil water loss (Chalker-scott, 2007; Akhtar et al., 2019; Massaccesi et al., 2020). Mulching with organic or inorganic materials aims to cover soils and forms a physical barrier to limit soil water evaporation, control weeds, maintain a good soil structure, and protect crops from soil contamination. Natural mulches are those derived from animal and plant materials. If effectively used, they can offer all the benefits of other types of mulches (Massaccesi et al., 2020).

The main benefits of mulching are early crop production, higher yields, better product quality, more efficient water use, reduced leaching of fertilizers, reduced soil and wind erosion, reduced herbicide application, weed control, and others related to pest and disease management (Lamont, 2005). Some of these benefits are especially relevant in organic farming. Crops from the Solanaceae (tomato, eggplant, and pepper) and Cucurbitaceae (melons, watermelons, squash, cucumber) families, strawberries, green beans, asparagus, and salads, among others, have shown significant gains when cultivated with mulch (Emmert, 1957). Polyethylene mulches are widely used in the cultivation of vegetables. Temperature moderation and salinity reduction are the desirable effects of plastic mulching. It also influences earliness, yield and quality of crop (Bhardwaj, 2013).

1.2 Statement of the problem
Tomato is the second most important and widely consumed exotic vegetable accounting for 20% by value of the exotic vegetables Tomato is cultivated on 18,378 Ha producing 330679 metric tons with average production of 18 metric tons per hectare. (HCD, 2017; FAO, 2016). Bungoma County is the third largest producer of
Tomato in the country cultivating 1,055 hectares producing 25,429 tons with an average production of 24 tons per hectare. (HCD, 2017). Tomato production in the county has been on the decline for the past five years, area under production reduced from 1344 hectares in 2012 to 811 hectares in 2016 while productivity reduced from 29 metric tons per hectare in 2012 to 24 metric tons per hectare in 2015 (HCD, 2017). Despite the favourable climatic conditions tomato yields in the county remain far below the potential yields range in open field production of 40 to 100 tons per hectare. Low adoption of technology, poor soil moisture management, pests and poor soil fertility management are the major challenges in tomato production in the county. Overall Better cultivars, more intensive use 100% glasshouse, computerized climate control, carbon dioxide enrichment, integrated crop protection, modern greenhouse structures, hydroponics, supplementary lighting and integrated pest management can increase tomato yields to over 400 tons per hectare per year (Heuvelink, 2005).

Based on the above analysis manipulation of growing environment has the potential to improve tomato yield. Mulching with inorganic and organic materials is one of the good cultural practices that manipulate root microclimate resulting in sustained soil moisture, regulated soil temperature, suppressed weed growth, minimized leaching of nutrients, checks excessive reduced soil erosion and improved productivity and quality (Bhardwaj, 2013). Tomato is among the most studied crop in the world. Studies on tomato mulching has been done for over 50 years under different climatic and environmental conditions and the effect of both organic and inorganic mulch on tomato growth and yield has been significant. Despite no such study has been done in Bungoma situation and climatic and environmental
conditions. There is need to evaluate the effect of organic and plastic mulch on prevalence of weeds, diseases incidences, growth and yield of tomato varieties. This study is relevant in the development of tomato value chain in Bungoma County.

1.3 General objectives
To evaluate the effect of organic and inorganic mulching on weeds, diseases, physiological disorders (BER), growth and yield of tomato varieties.

1.3.1 Specific objectives
i. To determine the effect of organic and inorganic mulching on growth and yield components of tomato varieties.

ii. To evaluate the effect of organic and inorganic mulching on weeds, disease incidences and physiological disorders (BER) of tomato varieties.

iii. To evaluate the effect of organic and inorganic mulching on soil moisture conservation.

1.3.2 Hypotheses
i. Organic and inorganic mulching has no significant effect on optimal growth and yield components and there are no variations in tomato varieties.

ii. Organic and inorganic mulching has no significant effect on weeds, bacterial wilt incidences and physiological disorders (BER) of tomato.

iii. Organic and inorganic mulching has no significant effect on soil moisture retention
1.4 Justification of the study

The Bungoma county department of agriculture has adopted the value chain development approach to enhance agricultural productivity, value addition and facilitate market access for enhanced income generation. Tomato production is among the key agricultural value chain with great potential to contribute towards transforming farmers livelihoods in the whole county. In that respect over 100 Green houses have been distributed to farmers groups and plans are underway to build a tomato processing plant to promote fresh and processing tomato production. The county enjoys good climate throughout the year with potential to achieve higher yields increase production area and expand controlled environment production systems.

To increase the current yield from 24 tons per hectare to the potential 60 tons per hectare deliberate efforts must be made to invest in technology such as green house, high yielding varieties, irrigation and intensive use of fertilizers and chemicals. The cost of these technologies is not affordable by many small holder farmers who apply minimal inputs. Climate is the predominant factor that determines crop production. Therefore, growers who can modify growing environment condition have a competitive advantage over growers in the same region that do not have the ability to manipulate growing environment condition. Manipulation of environmental condition can be achieved through a variety of cultural practices (Read, 2007). Among the cultural practices mulching is the one that involves placing organic or synthetic materials on the soil around plants to provide a more favourable environment for growth and production. Therefore, there is need to promote best
agricultural practices which are affordable with wide range of benefits such as mulching.

Tomato offers considerable economic returns for farmers in tropical regions especially when grown during seasons with high demand. However, yield of tomato varies according to the cultural management and with the variety used. The application of appropriate field cultural management practices and the choice of cultivars are the two factors that affect the productivity of tomato.

1.5 Conceptual framework

Figure 1.1. Conceptual framework
CHAPTER TWO: LITERATURE REVIEW

2.1 Origin and uses of tomato
The tomato (*Solanum lycopersicum*) belongs to the family Solanaceae (also known as the nightshade family), genus Lycopersicon, sub family Solanoideae and tribe Solaneae (Olmstead *et al.*, 2008). The Solanaceae family includes other important vegetable crops such as peppers (*Capsicum spp.*), potato (*Solanum tuberosum*), aubergine (*Solanum melongena*), tomatillo (*Physalis ixocarpa*) and tobacco (*Nicotiana tabacum*). Wild species of tomato are native to the Andean region that includes parts of Chile, Colombia, Ecuador, Bolivia and Peru (Costa and Heuvelink, 2005). The most likely ancestor is the wild *L. esculentum var. cerasiforme* (cherry tomato), which is indigenous throughout tropical and subtropical America. Although the ancestral forms of tomato grew in the Peru–Ecuador area, the first extensive domestication seems to have occurred in Mexico (Lang, 2004). The Spanish introduced the tomato into Europe in the early 16th century. In the 17th century, Europeans took the tomato to China, South and South-east Asia and in the 18th century to Japan and the USA (Caicedo and Peralta, 2013; Knapp and Peralta, 2016).

Tomato can play an important role in human diet. It is a valuable source of vitamins A and C, as well as several minerals including calcium, iron, manganese, and particularly potassium (Naika *et al.*, 2005). It also contains lycopene, which is a carotenoid (a pigment involved in photosynthesis) and that gives red colouring to tomatoes (Kelley and Boyhan, 2010). It also possesses medicinal properties, especially lycopene which lowers blood pressure, reduces stroke and acute coronary events and prevents some forms of cancer by lessening damage caused by free
radicals (Heuvelink, 2005). Tomatoes can be eaten fresh or in a multiple of processed forms, The processed forms include tomato preserves (e.g. whole peeled tomatoes, tomato juice, tomato pulp, tomato purée, tomato paste, pickled tomatoes), dried tomatoes (tomato powder, tomato flakes, dried tomato fruits) and tomato-based foods (e.g. tomato soup and tomato sauces) (Beecher, 1998; Motamedzadegan and Tabarestani, 2018) Tomatoes are commonly used as a ‘model crop’ for diverse physiological, cellular, biochemical, molecular and genetic studies because they are easily grown, have a short life cycle and are easy to manipulate (Heuvelink, 2005).

2.2 Overview of tomato industry
The global production of tomatoes (fresh and processed) has increased by about 300% in the last four decades. (FAO, 2016) The annual worldwide production of tomatoes in 2009 has been estimated at 150 million tons with a total production area of about 4.2 million hectares. It is possible that these figures underestimate the real production area and tonnage, considering that tomatoes are also grown on small plots and gardens for subsistence purposes. (Heuvelink, 2005). The three leading producers are China, the USA and Turkey. China accounts for about 25% of the world’s total production and cultivated area and it is also the largest consumer. The USA, Italy, Spain and Turkey dominate the world processing tomato industry. Italy is the leading tomato producer in Europe, with a production of 6.9 million tons, of which 70% is for processing (FAO, 2016).

The Netherlands is the world leader in intensification, with an annual average of 50 kg/m², and in many cases production exceeds 60 kg/m². The use of modern technology (100% glasshouse, computerized climate control, CO₂ enrichment and
integrated crop protection) characterizes this Dutch production system. Some growers use assimilation light to make year-round production possible. Growers are well-educated and organized and innovation is promoted by research that is often initiated by the companies themselves. Growers in The Netherlands focus on high quality segments and selling their produce more by contract than by auction. (Csizinszky, 2005). The major tomato producers in the Middle East and North Africa are Egypt, Tunisia, Morocco and Jordan. Egypt is the largest producer of tomatoes on the African continent with a total production of slightly over 6 million tons. The tomato production is mainly located in the bordering areas of the Nile Delta. (FAO, 2016).

In Kenya Tomato is cultivated on 18,378 Ha producing 330679 metric tons with average production of 21 metric tons per hectare (HCD, 2017). Bungoma County is the 3rd largest producer of tomato in the country cultivating 1,055 hectares producing 25,429 tons accounting for 7% by value of the country tomato production with an average production of 24 tons per hectare (HCD, 2017). Productivity levels for many crops in the country are below potential and for some crop yield over a 5-year period have either remained constant or are on the decline. The stagnation and decline is caused by Low absorption of modern technology and high levels of waste due to pre- and post-harvest losses (GoK, 2010).

Tomato yields are increasing worldwide because of better cultivars, more intensive use of modern technology (100% glasshouse, computerized climate control, CO₂ enrichment, integrated crop protection) and intensive use of capital and technology (modern greenhouse structures, computer-controlled systems, hydroponics,
supplementary lighting, integrated pest management. In general, greenhouse tomato yields are much higher than for outdoor production: 375 ton/ha/year compared with 100 ton/ha/year (Jensen and Malter, 1995). Yields in soilless greenhouse systems average higher than yields in soil-based greenhouse systems.

2.3 Tomato growth characteristics

Tomatoes growth habits is categorized as determinate growth or bushy which is mainly suitable for open field production (Elser, 2019). Indeterminate or vine tomato is usually for green house production require trellising and pruning because it continuously produces inflorescence and flowers throughout the plant lifetime. The main tomato varieties grown in Kenya can be categorized into those grown in greenhouses and those grown in the open field. Varieties grown in the green house include Anna F1, Nemoneta F1, Corazzon F1, Tylka F1, Claudia F1, Chonto F1 and Prostar F1 (Ochieng et al., 2016). In open field production system, the open pollinated (OPV) varieties commonly grown include Rio Grande and Cal-J supplied by a number of seed companies. This varieties have replaced earlier varieties such as Money Maker, Fortune, Kentom, Neema 1400, Neema 1200, Caltana, Manset, Rotade, which are no longer popular with farmers. Hybrids varieties such as Eden F1, Assila F1, Kilele F1, Valoria F1, Shanty F1, Nuru F1 and Tropicana F1 have been introduced to offer increased yield and disease tolerance.

Tomatoes varieties and cultivars exist for fresh production which range from small, sweet tasting cherry tomatoes to large beefsteak tomatoes with different colours, shelf-life and flavors (Heuvelink, 2005). Commercial tomato cultivar Cal-J is a determinate variety grown for both processing and fresh fruit in many regions in
Kenya. It is mainly an open field commercial type growing to a height of 80 cm bearing up to 50 fruits per plant. The variety matures after 80 to 120 days after planting. Cal J fruit is oval, red in colour, relatively stiff in firmness with a fruit average weight of about 70 grams. The potential yield for the variety goes up to 80 tons per hectare. Cal J is a popular variety among the traders and farmers for its vigorous growth and high yielding characteristics and long shelf live (Anonymous, 2015).

Tylka F1 is a semi determinate hybrid tomato ideal for outdoor and greenhouse production. Its Strong and open plant with medium foliage and highly responsive to fertilizer and irrigation. First bloom appears in 35-40 days. Mature 75 days after transplanting Production. Yield Average production of 70 - 80 tons per hectare under good agronomic practice. Has a long harvesting period of 4 to 6 months Fruit Elongated firm and oval fruit type, Good, sweet flavour. Fruit size range between 100-130 grams, Shelf life is over 21 days when harvested at mature green stage. Tylka F1 is resistant to the following diseases: Tomato yellow leaf curl virus, Tomato Mosaic Virus, Grey leaf spot, Fusarium crown and root rot ,Verticillium & Fusarium wilt (race 1 and 2) and Nematodes (Meloidogyne incognita) (Anonymous, 2015).

Tomatoes are adaptable plants but grow well in warm conditions with optimum temperatures of 15°C -25°C (Waiganjo et al., 2006). Extremely low temperature can delay colour formation as well as ripening while temperatures above 30°C inhibit fruit set, flavour and Lycopene development (Waiganjo et al., 2006). Tomatoes grow well in a wide range of soil types, which are high in organic matter, well-
drained and with a pH range of 5 to 7.5 and moderate rains (Al-Omran et al., 2010; Lee and Kennedy, 2020). Wet conditions increase disease incidences and affect fruit ripening. With the greenhouse technology, farmers are now able to utilize small pieces of land to produce high quality tomato for specialized markets (Murungi et al., 2016). Production of tomato is carried out in two main seasons based on availability of rains as well as anticipated pest and disease pressure. The main production areas for open field tomato types include Bungoma, Kirinyaga, Nyandarua, Kajiado and Narok counties with Mwea, Loitoktok and Rumuruti being the main production regions. Raised plastic tunnel production system is mainly practiced in the outskirts of Nairobi, Kajiado, Kiambu and Nakuru Counties (Ochilo et al., 2019; Gatahi, 2020; Mwangi et al., 2020b).

2.4 Mulching
The word mulch is derived from the German word “molsch” meaning soft to decay, which referred to the use of straw and leaves by farmers as covers on seed beds (Jacks et al., 1955). Mulching is the application of covering layer of material to the soil surface (Norman, 1992). To facilitate more retention of soil moisture and helps in control of temperature fluctuations, improves physical, chemical and biological properties of soil, as it adds nutrients to the soil and ultimately enhances the growth and yield of crops (DilipKumar et al., 1990). In addition, mulch can effectively minimize water vapour loss, soil erosion, weed problems and nutrient loss (Van Derwerken and Wilcox, 1988). Mulch materials used by traditional farmers include leaves, dried or fresh banana leaves, grass, straw, maize stalk, crop residues, ash, animal dung and household rubbish. Cereal straw and stalk, crop debris, sawdust, leaves, grass, maize stover, weeds, manure, Spanish moss, and various water plants.
In modern or commercial agriculture, inorganic mulches used include aluminium foil, asphalt, paper, glass wool, petroleum mulch and various polythene mulches such as black or transparent polythene sheets. The main types of mulches are organic materials obtained from plant and animal residues and inorganic materials which are usually synthetic in nature (Hossen et al., 2017; Kader, et al., 2017 Farjana et al., 2019).

Mulching could improve the crop stands and increase yield by providing an environment for optimal plant growth. Mulched and irrigated treatments have been shown to induce higher root growth in comparison with non-mulched and rain fed treatments (Kumara and Dey, 2011). The properties of some mulch benefit plant growth by preserving soil structure and acting as a barrier to the action of rainfall that can cause compaction and erosion. Less-compacted soil provides a better environment for seedling emergence and root growth (Kumara and Dey, 2011).

Mulching is an agricultural cropping practice that involves placement of organic or synthetic materials on the soil around plants to provide a more favourable environment for growth and production (Lightfoot, 1996, Bhardwaj, 2013, Paine, 1993). Farmers use mulching to improve the condition of agricultural soils by covering the surface with different kinds of materials for better crop production. Improvement of the soil physical environment contributes to better plant production (Kumar, 1990). Covering the ground with mulch may add organic matter to the soil, reduce weed growth and reduce erosion (Bhardwaj, 2013). Therefore, several kinds of organic mulches are widely used to control weeds and to enhance plant health (Kumar, 1990).
Natural mulches help in maintaining soil organic matter and tilth (Radcliff, 1991) and provide food and shelter for earthworms and other desirable soil biota (White, 2007). The most common materials used as a mulch cover are manufactured plastics, essentially black polyethylene. These plastics are produced from petroleum derivatives, which are non-renewable resources; they are not degradable, and thus persist and pollute the environment for exceedingly long periods. Therefore, after the crop harvest, the plastics must be removed from the field and transported to an authorized landfill. As an alternative to the disposal inconvenience associated with non-degradable mulch films, photodegradable plastic mulches were developed by adding additives to promote controlled degradation (Lamont, 1993). Availability of low-cost biodegradable mulch which can be mixed into soil after the growing period would eliminate the problems of collecting and disposing of used mulch material.

Farmers used lithic material to mulch their dry land field to avoid drought and to improve crop yield. Stones, gravel, pebbles, volcanic ash and cinder as well as other lithic materials have been used. The method not only reduces evaporation but also decreases wind erosion and surface runoff from fields (Lightfoot, 1996). Also, traditionally the farmers used organic materials such as dry leaf, paddy straw, paddy husk, saw dust, dry grass, dry sugarcane leaves, coconut husk, dry coconut leaves and paper for mulching.

Plastics are man-made long-chain polymeric molecules (Carnell, 1978). The word plastic comes from the Greek word “plastikos,” which means “able to be moulded into different shapes” (Lamont, 1993). According to the American Society for
Plasticulture, plasticulture is “the use of plastic in agriculture,” which includes but is not limited to plastic mulch films, drip irrigation tape, row covers, low tunnels, high tunnels, silage bags, hay bale wraps, and plastic trays and pots used in transplant and bedding plant production (Lamont, 1993). Plasticulture is the technology of the use of plastics in the agricultural sector. Tar-coated paper mulches began to be used in the late 1800s, long before polyethylene was available (Lightfoot, 1996). British scientist has made polyethylene as sheet film in 1938 (Lightfoot, 1996). The earliest method using organic and inorganic materials to modify the microclimate of crop was mulching (Emmert, 1956). These developments during the early 1950s gave rise to a new system of vegetable production known worldwide as plasticulture.

The largest volumes of agricultural plastics used today are in the form of plastic films (Carnell, 1978). Plastics were first introduced on a commercial scale in 1939. These include polyethylene, polyvinyl chloride, and ethylene vinyl acetate. Polyethylene plastic is made from polyethylene resin, which is in the form of pellets. The pellets are heated and processed into bendable sheets of plastic film. The widespread use of polyethylene (the principal type of plastic used today) is due to easy processibility, excellent chemical resistance, high durability, flexibility, and freedom from odour and toxicity (Kasairajan, 2012). The most used mulch films include low-density polyethylene, linear low-density polyethylene, and high-density polyethylene (Lamont, 1993). Global plastic consumption in the agriculture and related areas is very high. In 1999, for example, over 30 million acres of agricultural land were covered with the plastic mulch, and the figure has been increased significantly. It is estimated that 1 million tons of mulch film is used worldwide every year in agriculture (Halley et al., 2001).
Many other benefits to plant growth are associated with the altered conditions created by mulch. In addition to reducing competition from weeds, mulches are used to increase water infiltration, reduce evaporation, modify soil temperatures and increase crop yields (Allison, 1973). The colour of a given material can have a range of influences on soil temperature. Soil temperature fluctuations are especially important since they impact on physical, chemical and biological processes in the soil (Shinde, 1994). Some mulching materials can improve the structure and fertility as they are decomposed and incorporated into the soil. The selection of mulching materials must be undertaken carefully in organic production. Both natural and synthetic mulches are approved for the use in organic vegetable production under certain circumstances. Polyethylene film (mulch) to cover plant beds has been used for commercial production of fresh-market tomatoes since the 1960s (Geraldson et al., 1965).

2.4.1 Organic mulching

Organic mulching materials can be classified as mulches containing plant nutrients (Eneji et al., 2003, Domínguez 2004) and mulching materials without significant plant nutrient content (Smith et al., 2000). Non-nutritional organic mulches contain high cellulose and lignin content with low amount of nutrients. Agro-waste usually used for mulching are grass straw, wheat straw, rice straw, barley straw, millet straw, rice husk, bagasse, ground nut shell, sawdust, soybean husk, bean stalk, sunflower husk, jute waste, sawdust, wood chips, sugarcane trash, paper, maize and sorghum husks etc. The use of this organic mulching material not only improves the water status but reduces fluctuations in soil temperature and reduces weed growth.
This can improve root growth and indirectly improve vegetative growth, which contributes to high crop growth and yield. 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). Natural materials cannot be easily spread on growing crops and require considerable human labour (Bhardwaj, 2011). Expense and logistical problems have generally restricted the use of organic mulch in horticultural crop production with only limited use on a large commercial scale.

According to Acharya and Sharma (1994), higher soil porosity is important for commercial crop production because it results in better root growth and a subsequent higher uptake of Nutrients. Application of nutritional organic mulches such as vermi-compost and farm yard manure, which were shown to be able to increase the nutrient status of a plant (Pinamonti 1998, Arancon et al., 2004), and reduce nitrogen fertilization, suppression of weed growth (Baxter 1970), increased organic matter in the soil (Arancon et al., 2004), increased soil moisture and retention (Barzegar et al., 2002), temperature moderation and improved root growth (Acharya and Sharma 1994).

2.4.2 Inorganic/synthetic/plastic/polyethylene film mulching
Inorganic mulches are categorized as plastics / Polyethylene or geotextiles /polypropylene. Plastic mulches have been used as seed bed covers for commercial production of fresh-market tomatoes since the 1960s (Geraldson et al., 1965). A
wide range of plastic films based on different types of polymers have all been evaluated for mulching at various periods in the 1960s. LDPE, HDPE and flexible PVC have all been used and although there were some technical performance differences between them, they were of minor nature. Today most of the plastic mulch is based on LDPE because it is more economic in use.

In production system involving inorganic mulching, the raised beds are covered with a low- or high-density polyethylene film 0.35 mm thick. The most common polyethylene mulch colours are white, black and white-on-black. Black mulch is used when the crops are planted in the cooler part of the year, when the soil is cold. White-on-black is used in summer plantings. The full-bed polyethylene mulch system, especially when combined with staking and trellising, has several advantages over bare ground production. The mulch cover inhibits weed growth (except that of the nut sedge, *Cyperus sp.*), retains soil fumigants, improves moisture retention, reduces fertilizer leaching, prevents bed erosion and protects fruits from decay caused by soil-borne disease organisms. Mulching increased the rate of tomato basal branch appearance and led to earlier flowering and higher early yield compared with non-mulched plants (Wien and Minotti, 1987). Seasonal total yields have been increased by the large-scale adaptation of the full-bed polyethylene mulch system.

Apart from conventional black or white-on-black plastic films, aluminium, blue, orange, red, silver and yellow mulches have been studied for growing fresh-market tomatoes (Decoteau *et al*., 1989; Csizinszky and Schuster, 1995). The reflective and coloured mulches affect plant growth and development by increasing soil or above
ground temperatures. Among the limitations of using plastic mulch in field
production of tomatoes include the requirement of specialized equipment to lay it on
the raised bed, increased cost of production due to the cost of purchasing the
polyethylene film and environmental concerns regarding disposal of plastic mulch
after the last harvest (Splittstoesser and Brown, 1991).

Plastic film may be disposed of by disking, burning, physical removal, or by
removal and storage. Long-term degradable film builds up in the soil and interferes
with field operations. Burning in situ with a flame thrower is expensive and in many
areas burning the plastic is prohibited by environmental laws. Physical removal is
labour intensive and finding a disposal site is difficult. To avoid these disposal
problems, the feasibility of sprayable mulching using biodegradable latex sprays and
bituminous residues has been investigated (Stapleton, 1991).

2.5 Effect of mulch on plants, soils and weeds
2.5.1 Effect organic and inorganic mulching practices on plant growth
parameters
Huaisen et al. (2000) observed that polyethylene film mulching enhanced the
secondary root growth of wheat. Kathmale et al. (2000) found that growth
parameters of groundnut were significantly increased due to straw and polythene
film mulch. Kumar and Ngachan (2001) observed that the number of branches and
dry matter accumulation per plant were significantly higher under polythene
mulched condition than un-mulched condition in winter groundnut (Arachis
hypogaea) at Manipur valley.
Buyushan et al. (2002) at Shanxi (China) observed that plastic film and the mat of sorghum straw increased plant height, above ground and root dry matter weight and leaf number per plant significantly in maize crop. Rahman and Khan (2002) observed that water hyacinth and rice straw mulch to maize crop resulted in higher seedling emergence and grain yield. Verma (2002) at Jobner observed that the application of organic mulches viz., mustard and Tephrosia (*Tephrosia purpurea*) straw each at 5 t/ha to pearl millet crop proved significantly better over dust mulch and control with respect to plant height, dry matter accumulation per metre row and total tillers per plant at 60 DAS and at harvest.

Ghosh et al. (2003) observed that black polythene mulching increased germination and early crop growth of groundnut due to increase in soil temperature. Poonia (2003) at Nagaur (Rajasthan) observed that the application of Tephrosia weed mulch 4 t/ha to pearl millet crop improved the growth attributes over other moisture conservation practices.

### 2.5.2 Effect of organic and inorganic mulches on soil moisture conservation

Water is essential for plant growth, development and fruiting. The success of many crop-based enterprises relies on conservative and efficient use of water. Moisture retention is the most common reason for which mulch is applied to soil. Mulch is used to protect the soil from direct exposure to the sun which would evaporate moisture from the soil surface and cause drying of the soil profile. The protective interface established by the mulch stops raindrop splash by absorbing the impact energy of the rain, hence reducing soil surface crust formation. The mulch also slows soil surface runoff allowing a longer infiltration time. These features result in
improved water infiltration rates and higher soil moisture. An auxiliary benefit of mulch reducing soil splash is the decreased need for additional cleaning prior to processing of the herb foliage (Barker, 1990).

Organic and inorganic mulches have been shown to improve the moisture retention of soil. This extended water holding ability enables plants to survive during low rainfall periods. The use of plastic mulch can be improved if under-mulch irrigation is used in combination with soil moisture monitoring. The influence of rainfall events is not as great when plastic mulch is used, necessitating active irrigation management. Under mulch, irrigation of vegetable crops has been shown to improve crop yields more than overhead irrigation systems (Clough et al., 1990). Mulch enables the soil moisture levels to maintain for longer periods. Plastic mulch conserved 47.08% of water and increased yield by 47.67% in tomato when compared to un-mulched control (Friake et al., 1990). Palada et al. (2003) concluded that plastic mulching resulted in 33 to 52% more efficient use of irrigation water in bell pepper compared to bare soil.

Thakur et al. (2000) observed that different mulching materials such as grass, lantana leaves and plastic, helped bell pepper (Capsicum annuum cv. California Wonder) to perform better at water deficits from 25 to 75 per cent and plastic mulch had highest water use efficiency. Hatfield et al. (2001) reported a 34-50 per cent reduction in soil water evaporation because of crop residue mulching. Mulch slows down evaporation and reduces the irrigation requirement Chawla (2006), Khurshid et al. (2006), Muhammad et al. (2009) stated the same results that mulching improves the ecological environment of the soil and it avoids decrease in soil water
levels. Mulch cover reduces surface runoff and holds rainwater at the soil surface thereby giving it more time to infiltrate into the soil (Khurshid et al., 2006). Abu-Awwad (1999) showed that covering of soil surface reduced the amount of irrigation water required by the pepper and the onion crop by about 14 to 29 and 70 per cent, respectively.

2.5.3 Effect of organic and inorganic mulches on weed control
Mulching Reduce weed growth by providing a physical barrier, mulching reduces the m germination and nourishment of many weeds. The mulching operation favours in the reduction of weed seed germination, weeds growth and keeps the weed under control (Vander Zaag et al., 1986). Covering or mulching the soil surface can prevent weed seed germination or physically suppress seedling emergence. Loose materials such as straw, bark and composted municipal green waste can provide effective weed control (Merwin et al., 1995). Saw dust is a soil improver and weed suppressor as it conserves soil moisture, decreases run-off, increases infiltration and percolation, decreases evaporation and weed growth can be substantial under clear mulch (Waterer, 2000). White or clear mulch and green covering had little effect on weeds, whereas brown, black, blue or white on black (double colour) films prevented emerging weeds (Bond and Grundy, 2001). Ossom et al. (2001) also observed significant differences in weed control between mulched and non-mulched plots of eggplant.

Plastic mulches have the potential to alter soil temperature, crop water use, improve crop quality and in some cases reduce weed competition, thereby improving crop development and increasing yields (Lamont, 2005 and Ngouaajio and Ernest, 2004).
Black plastic mulch is both effective at warming the soil and reducing weed competition. Clear plastic mulch provides greater soil warming, but it does not reduce the weed competition (Lamont, 2005). Dark coloured mulching reduces the amount of light reaching the soil and thus inhibits weed germination and smothers emerging weeds.

Mechanical and physical weed management methods that are widespread in ecological farming have significant expenses, so we need to examine other methods under local circumstances to save expenses. The use of living plants, plant residues (straw, compost, mowed grass, processing by-products) and industry-origin materials (black polyethylene foil, paper, felt, different kinds of textile) as mulch. Each mulching material has different weed control effect. A black polythene film is one of the most effective methods for weed control, but its major disadvantage is a non-degradable. Organic mulch is readily available and is used for inter-row covering. Besides its shading effect it can provide nutrients to the soil. One of the most popular mulches is straw, by-product of plant production. In India, straw mulch increased yield of crop and water keeping capacity of the soil (Moitra et al., 1998).

**2.5.4 The effect of mulch colour on plant growth**

Mulching with black or clear plastic increased total plant growth and led to an increased rate of branching and early flowering in tomato (Wein and Minotti, 1987). Hassan et al. (1994) reported that mulching is practically beneficial in chilli production. They concluded that increased plant growth for mulched plants may be related to soil moisture content because plant dry weight was positively correlated
with soil temperature and moisture content. Higher yield of peppers was observed under clear plastic mulch followed by black and wavelength selective mulch treatments as compare to bare soil.

Black plastic mulch doubled the yield of tomatoes as well as increasing the amount of early production for some cultivars when compared with un-mulched control (Abdul-Baki et al., 1992). Higher tomato yields were reported when black plastic mulch and row covers were used together is partially due to increase in air and soil temperatures around the plant growing environment. Most suitable soil temperature distribution was observed by the application of clear plastic mulch and it was more effective on first blossoming and harvesting time, leaf area and total yield in squash, while lowest plant growth and yield values were observed in bare soil (Tuli and Yesilsoy, 1997).

Significant increase was observed in strawberry runners and fruits with the use of black plastic mulch as compared to clear plastic, white plastic and bare ground treatments (Himelrick, 1993). A general increase in plant growth and fruit size in hot peppers was observed using plastic mulch while clear plastic mulch increased the early and total yield by 39% and 19% respectively (Pakyurek et al., 1994). Farias-Larios et al., (1998) found increased fruit weight (2.94 kg) and yield 25.5 tons/ha in watermelon by the application of clear plastic mulch as compared to un-mulched soil. However, no change was observed in total soluble solids of watermelon fruits by different types of plastic mulches but both clear and white plastic mulch increased fruit length. Brown et al. (2001) reported arahat bell peppers grown on
black plastic mulch alone or in combination with drip irrigation increased pepper yields by 18 and 16 tons/ha respectively when compared with bare soil.

Ibarra-Jimenez et al. (2002) found that total yield of bell pepper was increased by black polyethylene mulch alone or combined with row covers by around 10 tons/ha compared with control. The treatments had a positive effect relative to control in leaf area, specific leaf area and net assimilation rate. Ibarra-Jimenez et al. (2004) reported that dry weight of cucumber plants grown under plastic mulch or mulch combined with row covers (at 50 and 110 days after seeding) were significantly different from bare soil plant.

2.6 Effect of mulch on crop productivity

2.6.1 Effect of organic and inorganic mulching on plant growth and yield

The combined effects of soil temperature, soil moisture and weed suppression not only work to improve crop growth but they also facilitate hand picking and lead to higher yield and increased fruit size (Scheerens and Brenneman, 1994). Growth, yield and nutrient uptake are affected by plastic mulching (Wein and Minotti, 1987). Karp et al. (2004) reported that mulching treatment significantly influenced nutrient content of leaves and chlorophyll contents (381 SPAD units) were significantly lower in control plants compared with plants grown on different mulches (498 and 542 SPAD units). Plastic mulches increased crop growth (3.2–4.0 cm), dry root mass (12.2–50.1%), nitrogen fixing activity (3.3–12.8%), leaf chlorophyll content (41–78%) more reproductive buds (63.3–94.1%) and starts flowering 9 days earlier in groundnut than un-mulched control (Hu et al., 1995).
Gupta and Acharya (1993) observed increased root mass under black polyethylene mulch was attributed to the resultant increase in soil temperature and nutrient uptake. Niu et al. (2004) concluded that improved productivity was related to increased root dry weight under mulches and larger rooting systems resulted in greater ability to take up water and nutrients that led to higher grain yield with mulched wheat. Plastic mulches improved stand establishment and fruit yields relative to un-mulched control. Vegetable crops grown under plastic mulches have shown earlier 7 to 14 days and increased yields 2 to 3 times over vegetable crops grown on bare soil (Lamont, 1993).

Mulches ameliorated soil hydrothermal regime, improved vegetative growth, advanced flowering and fruit yield of tomato plants when compared with bare soil (Agele et al., 2000). Kirnak and Demirtas (2006) both root and shoot dry weights of cucumber plants were significantly improved by plastic mulch. Ibarra et al. (2001) concluded that watermelon plants grown under plastic mulch and row cover showed greater plant biomass, specific leaf area, relative growth rate and net assimilation rate than bare soil plants. Similarly, time to anthesis was 45 and 55 days after sowing for black plastic mulch and control plants respectively. The number of leaves per plant or dry weight per plant better explains the changes in watermelon yield than net photosynthesis rate (Ibarra-Jimenez et al., 2005). Similarly, plant height, number and length of main roots, fresh and dry weights of roots as well as number of flowers were significantly higher in plants grown on mulch as compared to bare soil (Hasan et al. 2005). Leaf area ratio and leaf weight ratio were not significantly different in melon grown under plastic mulch but 10-20% higher than those on the bare soil (Munguia-Lopez et al., 2000).
Mulched plants usually grow and mature more uniformly than non-mulched plants (Bhardwaj et al., 2011; Sarolia and Bhardwaj 2012). Hassan et al. (1994) and Yamaguchi et al. (1996) revealed that combination of reflective film mulching and shading treatments increased plant height, length of primary and secondary branches of carnation seedlings. Lourduraj et al. (1996) obtained highest plant height (81.5 cm) and number of laterals (8.6 per plant) in tomato with the application of black polythene mulch as compared to organic mulch and no mulch. Similar results were also reported by Kim et al. (2000) in Crocosmia crocosmiiflora, Hong et al. (2001) in lilies. Gao et al. (2001) found out that the nutrient paper mulch advanced plant growth as compared to plastic mulch and no mulch in tomato. Organic mulches induced earliness in flowering, less days to fruit set and harvest in tomato crop over control (Ravinderkumar and Shrivastava, 1998).

2.6.2 Effect of organic and inorganic mulching on quality and yield
Mulch helps keep fruits clean from contacting the ground, reduces soil rot, fruit cracking and blossom end rot in many cases. Fruits tend to be smoother with fewer scars. Properly installed plastic mulch helps keep soil from splashing onto the plants during rainfall, which can reduce grading time. The yield and chemical composition of tomatoes, cucumbers, muskmelons, eggplant, were found to be improved. The yield and keeping quality of early potatoes, cabbage and other vegetables may be improved by straw mulch.

Gupta and Gupta (1987) observed that application of straw mulch at 6 tonnes per hectare increased yield of tomato and okra by 100 and 200 per cent, respectively over control. While at the same time marketable fruit yield from mulched plot was
significantly higher than those produced on bare soil. Gollifer (1993) reported that application of organic mulch at 40 tons per hectare produced 2.5 tons per hectare of chilli dry fruits. Hassan et al. (1994) reported that organic mulch gave higher fruit yield of bell pepper than control. The yield (27.9 per cent) and starch content (18.18 per cent) of potato was increased with paddy straw mulch over non mulched (Dixit and Majumdar, 1995). Aref et al. (1996) reported that application of hairy vetch mulch recorded significantly higher yield of tomato (32 per cent) than bare soil. Lourduraj et al. (1996) obtained highest number of fruits (42), average fruit weight (31.8 g) and yield (12.73 t ha⁻¹) in tomato cv. CO-3 with application of black polythene mulch compared to organic and no mulch. Mulching increased crop weight by 16 per cent compared with non-mulched plots in leek (Benoit and Ceustermans, 1998). Black polythene sheet (0.18 mm) mulching also increased 29 and 56 per cent flower yield of Anna and Sari varieties of roses, respectively (Rodrigues et al., 1999).

Thakur et al. (2000) reported that the use of different mulches on the performance of Capsicum annuum L. under water deficit of 75 per cent, the lantana mulch gave the highest fruit yield of 7.34 t ha⁻¹ over non-mulched plots (3.69 tons per hectare). They also reported that yield levels increased by 198 percent in plastic mulch, 164 percent in lantana leaves and 141 per cent in grass mulched plants over non mulched plants of capsicum. These findings agree with Gangwar et al. (2000) who reported that paddy straw mulch on mulberry showed maximum leaf yield (46%) compared to sorghum (32.4%) and black gram mulching (23.08%) over control. Murugan and Gopinath (2001) obtained maximum duration of flowering
and advanced flowering in *Crossandra cv. Saundrya* by using black polyethylene mulch as compared to organic mulches.

Gao *et al.* (2001) reported that the nutrient paper mulching promoted flower bud differentiation enhanced yield and improved fruit quality in tomato as compared to the plastic mulch or no mulching. Uppal *et al.* (2001) observed that mulched tubers of potato contained about 46 per cent less reducing sugars compared to normal crop. Nagalakshmi *et al.* (2002) obtained the maximum number of fruits per plant (97.67), length of fresh fruit (6.93 cm), circumference of fruit (3.57 cm) and yield of chilli (8.60 t ha-1) with the application of black polythene mulch compared to organic mulch and no mulch. Gandhi and Bains (2006) reported that the crop under straw mulch produced higher number of branches (8.7), fruit weight (28.08 g) and total yield (49.63 tons per hectare) as compared to no mulch (8.1, 27.86 g and 47.85 tons per hectare, respectively) in tomato. Chawla (2006) obtained highest number of flowers per plant (53.45), average flower weight (47.21 g/ 10 flowers), maximum flower diameter (5.47 cm) and highest flower yield (11.66 t ha-1) in marigold cv. Double mix with application of black polythene mulch compared to white polythene mulch, organic mulch and no mulch. Shashidhar *et al.* (2009) reported that the total leaf yield of mulberry was found maximum in paddy straw mulched plots 15.20 tonnes per hectare as compared to control plots 11.78 tonnes per hectare.

### 2.7 Effect of mulch on plant disease and physiological disorders

#### 2.7.1 Effect of mulching practice on incidences of Bacterial Wilt

Bacterial wilt is widely distributed in tropical, subtropical and some temperate regions of the world. Causal agent is *Ralstonia solanacearum* (Smith) (Yabuuchi *et
a highly diverse and adaptive bacterium, which differs in host range, geographical distribution, pathogenicity, epidemiological interactions and physiological properties (Buddenhagen et al., 1962). *Ralstonia solanacearum* is the causal agent of bacterial wilt in many crops (Hayward, 1994), and it is responsible for losses of up to 75% of the tomato crop in several countries (Cook and Sequeira, 1994. However, little is known about its distribution and persistence in relationship to mulching practices.

2.7.2 Effect of Mulching on incidences of physiological disorders (Blossom End Rot)

Tomato can be injured by two important physiological disorders, namely blossom end rot (BER) and Sunburn. (Adams and holder, 1992). Occurrence of these disorders results in unmarketable fruit and increased post-harvest loses and therefore limiting tomato production and quality (Adams and El-Gizway, 1988; Adams and Ho, 1989, 1995; Adams and Holder, 1992). BER was identified more than 100 years ago and there is s no effective method of controlling it (Saure, 2001). Many researchers associate the occurrence of BER in tomato to a deficiency of Ca\(^{2+}\) in the fruit or parts of the fruit in connection with the uptake of nutrients by the roots, the transport of Ca\(^{2+}\) to and within the fruit or a varying demand for Ca\(^{2+}\) depending on the growth rate of fruits (Saure, 2001). BER seems to occur when stress exceeds stress tolerance, most cases in young fruit at the beginning of cell enlargement (Saure, 2001). Adams and Ho, (1993) reported that BER is usually an interaction between the effects of irradiance and ambient temperature on fruit growth and the effects of environmental stress on Ca uptake and distribution within the whole plant.
When less water is available to the plant, Calcium uptake is reduced because Calcium flows through the plant with the water flow of transpiration. Transpiration is also depressed in conditions of high humidity when Calcium uptake by plants may be restricted. Increased light period and/or light intensity increases growth rate and this higher growth rate will increase the demand for Calcium. The tissue level of Calcium may fall below the critical level and induce Calcium deficiency symptoms in plants (Kleemann, 1999).

Tomato cultivars differ in the incidence of BER in their fruits with some being more susceptible to BER than others (Ho et al., 1993, 1995; Kirkby, 1979; Nonami et al., 1995; Nukaya et al., 1995). Early cultivars are more susceptible to BER (Magan et al., 2008). Susceptible cultivars tend to have a higher fruit load and larger fruit (Ho et al., 1995). These differences between cultivars result from cultivar differences in the daily rates of Calcium uptake, and the difference is more consistent in older plants (Ho et al., 1995). Determinate cultivars stop producing new fruit trusses early in the season, and Calcium then tends to move through the plant easily with the water flow of transpiration. Saure (2001) postulated that when growth rate is lower the incidence of BER is also lower, and Wiersum (1979) found that high growth rate is associated with reduction of Ca content in fruits.

Organic mulches have been found to decrease the incidence of Calcium deficiency in plants (Elmer and Ferrandino, 1991; John et al., 2005; Magnusson, 2002). Mulching results in adequate soil moisture throughout the season and thereby helps to reduce BER. Mulching increases soil temperature, and Adams and Ho (1993) reported that an increase in root temperature stimulated Calcium uptake in
proportion to water uptake. Increased Calcium uptake will decrease the incidence of BER.
CHAPTER THREE: MATERIALS AND METHODS

3.1 The experimental site
The experiment was conducted at Mabanga agricultural training Centre demonstration and trial farm (Figure 3.1). The experiment was done in two seasons the first season running from September 2015 to December 2015 and the second season running from December 2015 to March 2016. Mabanga Agricultural training farm is situated 8 kilometers East of Bungoma town along the Eldoret-Malaba Highway 350 km from Nairobi at Latitude 00.59°N and Longitude 34.62°E at an Altitude of 1530 metres above sea level. The Centre fall in the Sub Humid lower mid land zone (marginal sugarcane zone).

Figure 3.1. Map of Bungoma County locating the experimental site
3.2 Climate and weather

The climate of the region is semi humid characterized by moderate temperature range from 19°C to 21°C and the average rainfall range from 1729.82 mm to 2401.51mm. Mabanga receives a bimodal rainfall with the long rains coming between March and June and the short rain season coming between October and December.2012 rains (Tables 3.1 and 3.2).

Table 3.1: Rainfall (mm) received at Mabanga for the year 2015 and 2016 at Mabanga

<table>
<thead>
<tr>
<th>Year</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>12</td>
<td>43</td>
<td>68</td>
<td>352</td>
<td>174</td>
<td>193</td>
<td>145</td>
<td>85</td>
<td>166</td>
<td>228</td>
<td>260</td>
<td>118</td>
<td>1844</td>
</tr>
<tr>
<td>2016</td>
<td>103</td>
<td>72</td>
<td>69</td>
<td>343</td>
<td>205</td>
<td>208</td>
<td>54</td>
<td>212</td>
<td>162</td>
<td>135</td>
<td>119</td>
<td>trace</td>
<td>1682</td>
</tr>
</tbody>
</table>

Table 3.2: Temperature, Dew Point, Humidity and Cloud Cover at Mabanga

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Dew Point</th>
<th>Humidity</th>
<th>Cloud Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>(MAX)</td>
<td>(MIN)</td>
<td>0900hrs</td>
<td>1500hrs</td>
</tr>
<tr>
<td>30.38</td>
<td>14.08</td>
<td>13.88</td>
<td>12.63</td>
</tr>
</tbody>
</table>

The soil is deep well drained dark red to dark reddish brown, loamy sand in texture, acidic, poor in organic matter and low in available nitrogen (Table 3.3).
Table 3.3. Soil properties of study site (Mabanga Agricultural Training Centre)

<table>
<thead>
<tr>
<th>Element</th>
<th>Unit</th>
<th>Value</th>
<th>Range low</th>
<th>Range high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic carbon</td>
<td>g/kg</td>
<td>8.3</td>
<td>17</td>
<td>50</td>
</tr>
<tr>
<td>Magnesium exchange</td>
<td>Mmol+/kg</td>
<td>8.8</td>
<td>4.5</td>
<td>10</td>
</tr>
<tr>
<td>Potassium exch</td>
<td>Mmol+/kg</td>
<td>1.4</td>
<td>1.5</td>
<td>3.0</td>
</tr>
<tr>
<td>pH Value</td>
<td>pH value</td>
<td>5</td>
<td>4.9</td>
<td>6.4</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>Mmol+/kg</td>
<td>1.6</td>
<td>0.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Cation exchange capacity</td>
<td>Mmol+/kg</td>
<td>54</td>
<td>75</td>
<td>200</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>g/kg</td>
<td>0.81</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Zinc m³</td>
<td>Mg/kg</td>
<td>1.1</td>
<td>2.5</td>
<td>4</td>
</tr>
<tr>
<td>Copper m³</td>
<td>Mg/kg</td>
<td>2.1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Calcium exchange</td>
<td>Mmol+/kg</td>
<td>21.8</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Clay</td>
<td>g/kg</td>
<td>350</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>g/kg</td>
<td>580</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: The soil cares initiative info@soilcares.com, www.soilcares.com

3.3 Experimental design and treatments

The field experiment was laid out in a Randomized Complete Block Design (RCBD) in split-plot arrangement replicated three times. Two tomato varieties i.e. Cal J (Determinate) and Tylka F1 (Semi indeterminate) were main plot treatment while black polyethylene film mulch (standard management practice), white polyethylene film mulch (standard management practice), Sugarcane Trash at 3kg per meter square and No mulch were sub plot treatment. The treatments were randomly allotted to different plots using random number table. The layout plan of the experiment with allocation of treatments is shown in (Figure 3.2 and 3.3).
Figure 3.2: Experimental layout first season at Mabanga Agricultural Training Centre

Figure 3.3: Experimental layout second season at Mabanga Agricultural Training Centre

Tomato commercial cultivar Cal J is a determinate variety grown for both processing and fresh fruit in many regions in Kenya. It is mainly an open field
commercial type growing to a height of 80 cm bearing up to 50 fruits per plant. The variety matures after 80 to 120 days after planting. Cal J fruit is oval, red in colour, relatively stiff in firmness with a fruit average weight of about 70 grams. The potential yield for the variety goes up to 80 tons per hectare. Cal J is a popular variety among the traders and farmers for its vigorous growth and high yielding characteristics and long shelf life.

Tylka F1 is a semi determinate hybrid tomato ideal for outdoor and green house production. Its Strong and open plant with medium foliage and highly responsive to fertilizer and irrigation. First bloom appears in 35-40 days. Mature 75 days after transplanting Production. Yield Average production of 70 - 80 tons per hectare under good agronomic practice. Has a long harvesting period of 4 to 6 months Fruit Elongated firm and oval fruit type, Good, sweet flavour. Fruit size range between 100-130 grams, Shelf life is over 21 days when harvested at mature green stage. Tylka F1 is resistant to the following diseases: Tomato yellow leaf curl virus, Tomato Mosaic Virus, Grey leaf spot, Fusarium crown and root rot, Verticillium and Fusarium wilt (race 1 and 2) and Nematodes (*Meloidogyne incognita*).

3.4 Cultural operations

3.4.1 Field preparation
The field was ploughed and harrowed to attain relatively fine tilt, well decomposed manure was applied at the rate of 2kg/m² and planting fertilizer DAP applied at the rate of 200 Kg/ha was incorporated in the soil two weeks before raising beds in readiness for planting. Organic Mulch (Dry Sugarcane trash) was applied on the bed at the rate of 0.5 kg per m² while the polythene film 25 micron was placed to cover
the raised beds. The tomatoes were established at the spacing of 90 cm x 60 cm on raised bed.

3.4.2 Seedling Raising
The seedlings were raised in the cell trays for 4 weeks in the greenhouse on 21st August 2015 and 17th December 2015 respectively for the two growing seasons. Prior to transplanting the seedlings were transferred to the screen house for hardening.

3.4.3 Crop Management
Normal agronomic practices were applied to the tomato crop, top dressing in two splits at the rate of 100kg CAN per hectare, pest scouting was done and pest controlled appropriately. Tylka F1 Tomato plants were then trained to double stem by continuous removal of auxiliary shoots and staked.

3.5 Data collection
In order to evaluate the effect of treatments on weeds suppression, growth components, yield components, incidences of diseases and physiological disorders the following periodical data was collected on plant height, shoot weight dry and wet, stem thickness, number of branches, number of trusses, number of open flowers, fruit sizes (small, medium and large), Fruit weight (marketable and non-marketable), Soil moisture content, Bacterial wilt score, weeds dry weight, weeds wet weight, Blossom end rot and Sunscald scores. Measuring Tomato Growth Components Five randomly selected plants were tagged in each treatment plot for recording growth parameters and the mean of the observations on these 4 plants was computed and recorded.
3.5.1.1 Plant height
The height of tagged plants was measured in centimetres from the soil surface to the tip of the main shoot at 25 DAT, 60 DAT and 90 DAT. A ruler was used to measure the height.

3.5.1.2 Stem thickness
The thickness of the main stem of all tagged plants was measured in millimetres at 4 cm above the soil surface with the help of vernier calliper at 25 DAT, 60 DAT and 90 DAT.

3.5.1.3 Number of branches
The number of branches on each tagged plant was counted and mean number of branches per plant was recorded at 25 DAT, 60 DAT and 90 DAT.

3.5.1.4 Shoot dry weight
Electric oven dry weight (drying at 70°C for 72 hrs. to a constant weight) of whole plant after destructive sampling of one of the tagged plants at 25 DAT, 60 DAT and 90 DAT was measured using an electronic balance.

3.5.1.5 Shoot fresh weight
The shoot fresh weight was measured using electronic balance immediately after destructive sampling of one of the tagged plants.

3.5.2 Evaluating incidence of tomato Bacterial Wilt and Blossom End Rot
Identification of the tomato diseases and physiological disorders was done using CABI Plant wise Diagnostic procedure (Tylor, 2015). Visual disease rating was used
to score Diseases and physiological disorder incidence using Horsfall–Barratt Scale
(Horsfall, 1945) (Table 3.4) the diseased plants in a population of plants was scored
as a percentage of diseased plants in a field.

Table 3.4. The Horsfall–Barratt Scale

<table>
<thead>
<tr>
<th>Rating</th>
<th>% Infection</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0–3</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>3–6</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>6–12</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>12–25</td>
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</tr>
<tr>
<td>6</td>
<td>25–50</td>
<td>25</td>
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<tr>
<td>7</td>
<td>50–75</td>
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<td>8</td>
<td>75–87</td>
<td>12</td>
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<td>9</td>
<td>87–94</td>
<td>7</td>
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<td>94–97</td>
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<tr>
<td>11</td>
<td>97–100</td>
<td>3</td>
</tr>
<tr>
<td>12</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

3.5.3 Measuring tomato yield components

Four tagged plants were used for recording yield parameters. The following data
were recorded.

3.5.3.1 The number of open flowers

The total number of open flowers from four tagged plants were counted and
recorded.

3.5.3.2 Number of trusses per plant

The number of trusses (flower clusters) on the tagged plants were counted and
record.
3.5.3.3 Fruit weight and fruit size per plant
The fresh fruit weights of fruits harvested from two plants from each experimental plot were summed up and average was computed and recorded as fruits weight per plant. subsequently the fruits were grouped into grades as per their sizes were large sizes were fruits weighing over 85 grams medium sized fruits weighing between 60g and 84 grams and small fruits weight less than 60 grams The weight was taken by using electronic balance.

3.5.3.4 Marketable and non-marketable fruits per plant
Tomato fruits harvested from two tagged plants were sorted into marketable and unmarketable, counted and weighed. Small sized Fruits below 60g, the damaged fruits were grouped as unmarketable. The Mean number and weight of marketable and unmarketable fruits were calculated from the total number and weight of marketable and unmarketable fruits.

3.5.3.5 Weight of fruit per hectare
The weight of fruits per plot was used to compute the weight of fruits per hectare and expressed in Kg/ha.

3.5.4 Soil moisture determination
Soil moisture was determined by the gravimetric method (oven drying method, w/w) down to a depth of 10-15cm before sowing of the seeds and thereafter, 2-week interval. A representative quantity of the moist sample was collected, immediately weighed and recorded as “wet weight of sample”. The wet sample was dried to a constant temperature not exceeding 115°C using an oven for 24 hours. After drying it was allowed to cool. The cooled sample was weighed again up to a constant value
and the sample recorded as the “dry weight of sample” four locations in each treatment was randomly be taken to determine soil water content.

3.5.6 Determination of weed population
Weed count per metre square and dry and fresh weight of weeds was determined. At 30 and 60 DAT (days after transplanting), weed samples were collected from two 50 cm × 50 cm quadrants randomly laid per plot. The weeds were identified up to species level and were clipped at soil surface, oven-dried at 80°C for 48 hours and weighed to determine the dry matter (DM).

3.6 Data analysis
Collected data was entered into an MS Excel sheet then cleaned and arranged for analysis. To determine significance difference among treatments, analysis of variance using SAS computer software was done and means separated at 95% confidence level using Fischer’s Protected LSD test where significant differences were observed. All statistical analyses were performed using SAS Version 9.2. Means were separated following the Fisher’s Protected Least Significant Difference (LSD) at 5% Test. Figures and tables were generated using both excel and R software version 3.4.1 for easy of results interpretation.
CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Effect mulching on tomato yield and growth components

4.1.1 Plant height

In season 1, there was no significant differences (P value > 0.05) in tomato plant heights at 25 days after transplanting under no mulch as well as at different mulch types for both Cal J and Tylka F1 tomato varieties. The height for the tomatoes ranged from 45 cm to 53 cm (Figure 4.1.1A). However, at 60 days after transplanting, sugarcane trash mulch was the best performed in height for both Cal J (82 cm) and Tylka F1 (144 cm), during this period, the poorly performed mulching material was black polythene mulch which recorded a height of 76 cm and 130 cm for Cal J and Tylka F1 tomato varieties, respectively. However, just like at 25 days after transplanting the differences observed at 60 days after transplanting were not significant (P value > 0.05) (Figure 4.1.1B). In both cases the interaction of varieties and mulching materials on plant height was not significant (P value > 0.05) (Figure 4.1.1).
Figure 4.1.1: Tomato plant height (cm) under different mulching materials in season1. 25DAT- 25 days after transplanting, 60DAT-60 days after transplanting. ns (P value > 0.05).
In Season 2, at 25 days after transplanting, the best performed mulching material in terms of plant height for Cal J tomato variety was the black polythene mulch (28 cm), similarly the black polythene mulch was the best for Tylka F1 variety (35 cm). In Cal J there were no significant differences in height for different mulches as well as under no mulch (P value > 0.05), a similar case was observed in Tylka F1 tomato variety. The interaction of the tomato varieties with different mulches on the tomato plant height was also not significant (P value = 0.75) (Figure 4.1.2A).

At 60 day following transplanting, different mulches; black polythene, sugarcane trash and white polythene performed better in height for Cal J tomato variety (55.5 cm, 49.5 cm and 46.8 cm, respectively) compared to no mulch (40.4 cm). However, a significant difference was only observed between black polythene mulch and no mulch (P value ≤ 0.05). There were no significant differences in height for between sugarcane trash and no mulch as well as white polythene mulch and no mulch nor that of both sugarcane trash and white polythene mulch to black polythene mulch (P value > 0.05). In Tylka F1, just like Cal J tomato, different mulches; white polythene, black polythene and sugarcane trash performed better in height (91.3 cm, 91.0 cm and 89.5 cm, respectively) compared to no mulch (80.3 cm). However, the only significant difference in height was observed between white polythene mulch and no mulch (P value ≤ 0.05). The interaction of tomato variety with mulching materials on the plant height was not significant (P value = 0.4) (Figure 4.1.2B).
Figure 4.1.2: Tomato plant height (cm) under different mulching materials in season 2. 25DAT-25 days after transplanting, 60DAT-60 days after transplanting. *(P value ≤ 0.05), ***(P value ≤ 0.01), ns (P value > 0.05).
The difference in varietal height as observed in the study can be attributed to inherent varietal characteristics. This study is consistent with Habtamu et al. (2016) who observed that phonological traits of tomato were significantly affected by both mulch and variety; they further reported that mulch and variety interaction influenced plant height and number of lateral branches. This study is consistent with the finding of Tswanya et al. (2017) which indicated that plant height of tomato was significantly increased by mulching; however, type of organic mulching material had no significant influence on the number of flowers of tomato plant.

Liasu et al. (2007) reported that mulched plants exhibit the highest plant height when compared with mom mulched plants. In another study by Kayum et al. (2008) inorganic mulching significantly influenced tomato growth and yield components. Organic and inorganic mulching effectively reduces evaporation, conserving soil moisture, increased nutrient uptake by the robust rooting system, minimized weed competition and modified hydro thermal regime of the soil all providing ideal conditions for greater plant growth and yields (Ossom, 2001).

4.1.2 Number of lateral branches and stem thickness
The numbers of lateral branches were significantly higher in white polythene mulch compared to all the other treatments in Cal J tomato variety (P value ≤ 0.05) in season one, but this was absent in season two. The differences in lateral branches for this variety among no mulch, black polythene, and sugarcane trash much were not significant (P value > 0.05) in both season one and two. On the other hand, there were no significant differences among the mulch treatments on the number of lateral branches for Tylka F1 variety in both season one and two. The interaction of tomato
variety with mulching material had a significant influence (P value = 0.013) on lateral branching of tomatoes in season one (P value = 0.013) but this was absent in season two (P value = 0.3) (Figure 4.1.3).

In terms of stem thickness, different mulching materials did not have significant influence on the stem thickness for both Cal J and Tylka F1 tomato varieties in both season one and season two (P value > 0.05). Similarly, the interaction of the tomato varieties and mulching materials did not have a significant influence (P value > 0.05) on the stem thickness of the tomato plants (Figure 4.1.4).
Figure 4.1.3: Number of main branches of tomato varieties under different mulching materials in season 1. (A) and 2 (B). 60 DAT- 60 days following transplanting. **(P value ≤ 0.01), *** (P value ≤ 0.001). ns (P value > 0.05).
Figure 4.1.4: Stem thickness (cm) of tomato varieties under different mulching materials in season 1. (A) and 2 (B). 60 DAT- 60 days following transplanting. ns (P value > 0.05).
This study is in agreement with similar study by Bhardwaj et al. (2011), Yamaguch et al. (1996), Lourduraj et al. (1996) who revealed that organic and inorganic mulching increased plant height and number of branches. Lourduraj et al. (1996) obtained highest plant height (81.5 cm) and number of laterals (8.6) per plant in tomato with application of black mulch. Chawla (2006) obtained maximum plant height (70.9 cm) plant spread (53.05cm) and the height number of branches (18.54) at harvest in marigold mulched with black plastic mulch compared to other mulching treatment.

4.1.3 Number of trusses
There were no significant differences in the number of trusses (P value > 0.05) among plots covered by organic and inorganic. However, plots with no mulch registered significantly lower number of trusses during season 2. The highest number of trusses (13.83) was recorded in plots covered by inorganic mulch (white polythene mulch) while the lowest number of trusses (9.66) was recorded on tomatoes grown in plots that had no mulch at 25DAT. The numbers of truss were significantly different between varieties (23.58), (11.58) and (14.33) (11.17) for Cal–J and Tylka F1 and for season one and two respectively (Table 4.1.1).
Table 4.1.1: Mean number of trusses in plots covered by different mulching types and tomato varieties

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Season 1</th>
<th>Season 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TS 25DAT</td>
<td>TS 25DAT</td>
</tr>
<tr>
<td>Cal- J</td>
<td>23.58a</td>
<td>14.33a</td>
</tr>
<tr>
<td>Tylka F1</td>
<td>11.58b</td>
<td>11.17b</td>
</tr>
<tr>
<td>LSD</td>
<td>4.04</td>
<td>1.52</td>
</tr>
<tr>
<td>No Mulch</td>
<td>14.83a</td>
<td>9.66b</td>
</tr>
<tr>
<td>Black Polythene Mulch</td>
<td>19.17a</td>
<td>13.33a</td>
</tr>
<tr>
<td>White Polythene Mulch</td>
<td>21.00a</td>
<td>13.83a</td>
</tr>
<tr>
<td>Sugarcane Trash Mulch</td>
<td>17.33a</td>
<td>12.83a</td>
</tr>
<tr>
<td>LSD</td>
<td>9.83</td>
<td>2.95</td>
</tr>
<tr>
<td>MXV</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Means followed by the same letter within the same column are not significantly different at 0.05 level of significance. *(P value ≤ 0.05), NS (P value > 0.05). DAT (Days After Transplanting) TS-Trusses, OP-open flowers, V- tomato varieties, M- mulching types.

4.1.4 Shoot weight and total plant weight

Significant differences (P value ≤ 0.05) between varieties on shoot weight and total plant weight were observed during the first season and not the second season table (4.1.2) Tylka F1 variety recorded the highest shoot and total plant weight 1352 g and 5006 g respectively. No Significant differences (P value > 0.05) between mulching types were observed during the first and second season. However non mulched plots recorded the lowest values of shoot and total plant weight compared with mulched plots. The differences in the shoot and total plant weight can be attributed to the morphological differences between varieties.
Table 4.1.2: Mean shoot weight and total plant weight in plots covered by different mulch types and tomato varieties

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Season 1 (SW60DAT)</th>
<th>Season 1 (TPW60DAT)</th>
<th>Season 2 (SW60DAT)</th>
<th>Season 2 (TPW60DAT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cal- J</td>
<td>954.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3539&lt;sup&gt;b&lt;/sup&gt;</td>
<td>549&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2071.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tylka F1</td>
<td>1352.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5006&lt;sup&gt;a&lt;/sup&gt;</td>
<td>560&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2135.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>LSD</strong></td>
<td><strong>266.1</strong></td>
<td><strong>980</strong></td>
<td><strong>62.9</strong></td>
<td><strong>246.6</strong></td>
</tr>
<tr>
<td>No Mulch</td>
<td>1092.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3777.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>476.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1748.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Black Polythene Mulch</td>
<td>1267.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4376.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>555.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2208&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>White Polythene Mulch</td>
<td>1317.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5094.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>608.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2325&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sugarcane Trash Mulch</td>
<td>1134.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3844.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>506.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2130&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>LSD</strong></td>
<td><strong>464.1</strong></td>
<td><strong>1635.3</strong></td>
<td><strong>66.0</strong></td>
<td><strong>210.9</strong></td>
</tr>
<tr>
<td><strong>MXV</strong></td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Means followed by the same letter within the same column are not significantly different at 0.05 level of significance. *(P value ≤ 0.05), NS (P value > 0.05). DAT (Days After Transplanting) SW- Shoot Weight, TPW-total plant weight, V- tomato varieties, M- mulching types.

This study results agrees with other studies by Buyushan et al. (2002), Rahman and Khan (2002), Verma 2002, Poonia (2003) which reported that organic and inorganic mulching significantly increased growth parameters (number of branches, dry matter content and plant height) of groundnuts, maize, tomatoes and pearl millet. Awodoyin et al. (2007) also reported that mulched tomato plants had more branches than the un- mulched plants, which supported the present results. Similar results were reported by Hamid et al. (2012) who found out that plants grown over plastic mulches considerably produced the greatest number of leaves relative to control treatment. This can be attributed on the soil hydrothermal modifications by
mulching materials which enhance root development and high absorption of plant nutrients from the soil which then promote faster growth.

4.1.5 Number of open flowers at 25 days after transplanting
The number of open flowers at 25 days after transplanting fruits showed no significant differences (P value > 0.05) between the mulching treatments in the two varieties for both seasons (Figure 4.2.1). This study is not in agreement with the studies of Goreta et al. (2005), McCann et al. (2007), Romic et al. (2003) Walter (2003), Tarara (2000), and Lamont, (2005) who reported that inorganic mulch and in particular black mulch promoted early growth and flowering.
Figure 4.2.1: Number of open flowers 25 days after transplanting under different mulch types and tomato varieties. A-Season 1 B-Season 2. ns (P value > 0.05).
4.1.6 Total fruit weight per plant

The total fruit weight per plant showed no significant differences (P value > 0.05) between varieties and between treatments in the first and second season. However that Tylka F1 recorded the highest total fruit weight per plant while inorganic mulching recorded the highest total fruit weight (3877.54 g, 3308.17 g, 1724.87g, 1724g) per plant compared to organic mulching and control in the first and second season (Table 4.2.1). The finding of this study is in agreement with report of Lourduraj et al. (1996) who found out that inorganic mulching recorded the highest number of fruits, average fruit weight and yield. It also confirms the finding of Benoit and Ceustermans (1998) who reported that inorganic mulching increased yield by 56% while organic mulching increased yield by 16% over no mulch treatment.
Table 4.2.1: Mean Total fruit weight per plant in plots covered by different mulch types and tomato varieties

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Season 1</th>
<th>Season 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cal J</td>
<td>2586.0a</td>
<td>1522.0a</td>
</tr>
<tr>
<td>Tylka F1</td>
<td>3655.0a</td>
<td>1575.0a</td>
</tr>
<tr>
<td>LSD</td>
<td>801.4</td>
<td>190.0</td>
</tr>
<tr>
<td>No Mulch</td>
<td>2485.04a</td>
<td>1552.13a</td>
</tr>
<tr>
<td>Black Polythene Mulch</td>
<td>3308.17a</td>
<td>1724.87a</td>
</tr>
<tr>
<td>White Polythene Mulch</td>
<td>3877.54a</td>
<td>1724.11a</td>
</tr>
<tr>
<td>Sugarcane Trash Mulch</td>
<td>2785.67a</td>
<td>1646.09a</td>
</tr>
</tbody>
</table>

Means followed by the same letter within the same column are not significantly different at 0.05 level of significance. *(P value ≤ 0.05), NS (P value > 0.05). FT-no fruits, TFW-total fruit weight, V- tomato varieties, M- mulching types.

Organic and inorganic mulching improves physical, chemical and biological properties of soil, as it releases nutrients to the soil and ultimately facilitates the growth and yield of crops (Dilipkumar et al., 1990). Black mulch reflects less short-wave radiation (10%) and absorbs more radiation (90%) than any other coloured mulch (Teasdale, 1995). Dark coloured mulches (black or red) typically have higher surface temperatures than clear or white mulch (Decoteau et al., 1989). The heat absorbed by dark coloured mulches is conducted to the soil surface, which raises the soil temperature (Tarara, 2000). White mulch absorbs only 5% of short-wave radiation, reflects only 11%, but transmits 84% of short-wave radiation (Tarara, 2000). White plastics mulch heat the soil by transmitting light to the soil surface, rather than conducting heat like black plastics (Ham and Kluitenberg, 1994).
Therefore, white mulch results in higher daytime soil temperatures than black plastic mulch (Liakatas *et al.*, 1986; Ham *et al.*, 1993).

Organic mulching materials maintain adequate infiltration rates, prevent surface crusting, improve aggregation of soil and modify the transport and retention of water, heat and air in the soil (Agyenim-Boateng and Dennis, 2001). organic mulching reduce high soil temperature, controls soil erosion by reducing runoff and heavy impact of rain drops and preventing leaching of nutrients, promoting the activities of soil microorganisms as well as reducing weed competition (Agyenim-Boateng and Dennis, 2001).

### 4.1.7 Number of marketable and non-marketable fruits per plant

There was no significant difference (P value > 0.05) between varieties and between the mulching treatments on the number of non-marketable fruits per plant in both seasons (Table 4.2.2). However, Tylika F1 had the highest number of marketable fruits per plant (32.6) in season one compared with Cal-J variety (30.5). Inorganic mulching recorded the highest number of marketable fruits (35.18) and (20.83) per plant for season and one and two respectively compared with organic mulching (sugarcane trash) which recorded (29.26) and (19.33) respectively in season and two. At the same time inorganic mulching recorded the lowest number of non-marketable fruit (14.41) and (14.17) respectively for season and two while organic mulching recorded higher number of (16.78) and (17.17) number of non-marketable fruits per plant for season one and two respectively. This is attributed to the hydrothermal modification of below and above ground environment of the growing tomato by inorganic mulch.
### Table 4.2.2: Mean number of marketable and non-marketable fruits per plant in plots covered by different mulch types and tomato varieties

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Season 1</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MF</td>
<td>NMF</td>
<td>MF</td>
<td>NMF</td>
</tr>
<tr>
<td>Cal J</td>
<td>30.5\textsuperscript{a}</td>
<td>15.02\textsuperscript{a}</td>
<td>20.33\textsuperscript{a}</td>
<td>17.8\textsuperscript{a}</td>
</tr>
<tr>
<td>Tylka F1</td>
<td>32.6\textsuperscript{a}</td>
<td>16.03\textsuperscript{a}</td>
<td>18.83\textsuperscript{a}</td>
<td>16.0\textsuperscript{a}</td>
</tr>
<tr>
<td>LSD</td>
<td>6.93</td>
<td>3.42</td>
<td>3.20</td>
<td>5.92</td>
</tr>
<tr>
<td>No Mulch</td>
<td>28.81\textsuperscript{a}</td>
<td>16.28\textsuperscript{a}</td>
<td>17.83\textsuperscript{a}</td>
<td>19.67\textsuperscript{a}</td>
</tr>
<tr>
<td>Black Polythene Mulch</td>
<td>32.83\textsuperscript{a}</td>
<td>14.63\textsuperscript{a}</td>
<td>20.33\textsuperscript{a}</td>
<td>16.50\textsuperscript{a}</td>
</tr>
<tr>
<td>White Polythene Mulch</td>
<td>35.18\textsuperscript{a}</td>
<td>14.41\textsuperscript{a}</td>
<td>20.83\textsuperscript{a}</td>
<td>14.17\textsuperscript{a}</td>
</tr>
<tr>
<td>Sugarcane Trash Mulch</td>
<td>29.26\textsuperscript{a}</td>
<td>16.78\textsuperscript{a}</td>
<td>19.33\textsuperscript{a}</td>
<td>17.17\textsuperscript{a}</td>
</tr>
<tr>
<td>LSD</td>
<td>9.85</td>
<td>4.98</td>
<td>4.65</td>
<td>8.54</td>
</tr>
<tr>
<td>MXV</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Means followed by the same letter within the same column are not significantly different at 0.05 level of significance. NS (P value > 0.05), NMF- number of marketable fruits/plants, NNMF-number of non-marketable fruits per plant, V- tomato varieties, M- mulching types.

This study agrees with Gupta and Gupta, (1987) report which indicates that inorganic mulching increased yield of tomato and okra by 100 and 200 \% respectively and the marketable yield was significantly higher that control treatment. This attributed to the ability of inorganic mulching to exclude contaminants, disease causing organism from the plant and ability to minimize blossom end rot. The marketable and total yield of n muskmelon was highest for polythene-mulched plants and lowest for control plant. This probably indicates that soil-accumulated heat might be more related to plant growth and yield than air-accumulated heat (Jenni et al., 1996).
Similar observation has been recorded by Melek and Atilla (2009) where earlier flowering and fruit formation were first observed with inorganic mulch. Hebtamu et al. (2016), John et al. (2005), also reported that yield and yield related traits such as number of cluster per plant, number of flowers per truss, number of fruits per cluster, marketable and fruit per yield per hectare were significantly affected by mulch and variety. John et al. (2005), justified that difference in varieties have inherent potentials for production of cluster and consequently fruits. On the contrary to this study Kayum et al. (2008), Wahome et al. (2001), Wang et al. (2010) and Hebtamu et al. (2016) reported that using organic mulch produced the highest number of tomato fruits and flower clusters per plant.

4.1.8 Fruit size
In the first season, the interaction of tomato varieties with mulching materials did not have a significant influence on the number of small fruits (P value = 0.3), the number of medium sized fruits (P value = 0.56), as well as the number of large fruits (P value = 0.83) (Figure 4.2.2). In Cal J, different mulching materials (black polythene, white polythene and sugarcane trash) as well as no mulch did not have significant differences in the number of small fruits (P value > 0.05). However, the number of small fruits was significantly higher (P value ≤ 0.05) in Tylka F1 tomato variety under sugarcane trash mulch compared to black polythene mulch. In this variety the number of small fruits under sugarcane trash mulch was not significantly different (P value > 0.05) form that observed under no mulch and black polythene white polythene mulch (Figure 4.2.2).
In Cal J tomato variety, the number of medium sized fruits was high under white polythene mulch compared to no mulch (P value ≤ 0.05), however, it did not vary from black polythene and sugarcane trash mulch (P value > 0.05). Similarly, there was no difference in number of medium sized fruits in this variety among no mulch, black polythene mulch and sugarcane trash mulch (P value > 0.05). On the other hand, there were no significant differences (P value > 0.05) in the number of medium sized fruits in Tylka F1 variety among different mulch treatments (Figure 4.2.2).

The number of large sized fruits in Cal J and Tylka F1 tomato varieties were significantly higher (P value ≤ 0.05) under white polythene mulch compared to other mulch treatments (no mulch, black polythene mulch and sugarcane trash mulch). The differences in the number of large fruits among no mulch, sugarcane trash mulch and black polythene mulch for the two varieties were not significant (P value > 0.05) (Figure 4.2.2).
Figure 4.2.2: Distribution of different fruits sizes per plant under different mulch types and tomato varieties in season1 *(P value ≤ 0.05), ***(P value ≤ 0.01), ***(P value ≤ 0.001), ns (P value > 0.05).
In the second season, the interaction of tomato varieties with mulching materials did not have a significant influence on the number of small fruits (P value = 0.69), the number of medium sized fruits (P value = 0.74), as well as the number of large fruits (P value = 0.54) (Figure 4.2.3). In both Cal J and Tylka F1, different mulching materials (black polythene, white polythene and sugarcane trash) as well as no mulch did not have significant differences in the number of small fruits (P value > 0.05) (Figure 4.2.3).

In both Cal J and Tylka F1 tomato varieties, the number of medium sized fruits was high under white polythene mulch compared to no mulch (P value ≤ 0.05), however, it did not vary from black polythene and sugarcane trash mulch (P value > 0.05). Similarly, there was no difference in number of medium sized fruits in this varieties among no mulch, black polythene mulch and sugarcane trash mulch (P value > 0.05) (Figure 4.2.3).

The number of large sized fruits in Cal J was significantly higher (P value ≤ 0.05) under white polythene mulch compared to other mulch treatments (no mulch, black polythene mulch and sugarcane trash mulch). The differences in the number of large fruits among sugarcane trash mulch and black polythene mulch for this variety were not significant (P value > 0.05), however, the difference in the number of large fruits between black polythene mulch and no mulch was significant (P value ≤ 0.05). On the other hand, there were no significant differences (P value > 0.05) among different mulches (black polythene, white polythene and sugarcane trash mulch) and no mulch on the number of large fruits in Tylka F1 tomato variety (Figure 4.2.3).
Figure 4.2.3: Distribution of different fruits sizes per plant under different mulch types and tomato varieties in season 2. *(P value ≤ 0.05), **(P value ≤ 0.01), ***(P value ≤ 0.001), ns (P value > 0.05).
This result is attributed to the hydrothermal modification of the above and below ground environment of the white mulched tomato plots. Under these mulching conditions plants were able to assimilate more photosynthetic products due adequate moisture, absorbed nutrients and greater net solar radiation. White polythene mulches are more effective in increasing soil temperature due a greater net radiation under the mulch compared to opaque mulches (Streck et al., 1994). Consequently, the soil heat flux is substantially greater under transparent mulch. Liakatas et al. (1986) reported that the maximum soil heat flux was up to 67% higher under transparent mulch in comparison to the black mulch. White PE used in this study trended to increase maximum temperature compared to the other opaque mulches (black and co-extruded white-on-black PE). This increase probably occurred due to the white PE is not completely opaque. It is expected that white and co-extruded white-on-black PE have a similar effect on soil temperature.

4.1.9 **Weight of Marketable fruits**
There were significant differences (P value ≤ 0.05) observed between the mulching treatments on the weight of marketable fruits of the two tomato varieties (Table 4.2.4). The highest weight of the marketable fruits was recorded in plots covered with the white polythene mulch of Tylka F1 variety in both seasons while the control (No mulch) had the lowest in both varieties.
Table 4.2.4: Mean weight of marketable fruits per plant in plots covered by different mulch types and tomato varieties

<table>
<thead>
<tr>
<th>Variety</th>
<th>Treatment</th>
<th>Season 1</th>
<th>Season 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cal-J</td>
<td>Black Polythene</td>
<td>2918&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>1874&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>No Mulch</td>
<td>1869&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1310&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Sugarcane Trash</td>
<td>2509&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1620&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>White Polythene</td>
<td>3259&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2197&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Tylka

<table>
<thead>
<tr>
<th>Variety</th>
<th>Treatment</th>
<th>Season 1</th>
<th>Season 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Black Polythene</td>
<td>2859&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>1887&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>No Mulch</td>
<td>2377&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1058&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Sugarcane Trash</td>
<td>3214&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1647&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>White Polythene</td>
<td>3528&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2279&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

LSD | 683.9 | 390.6 |

P Value | 0.043 | <.001 |

**Variety x Treatment** | * | * |

Means followed by the same letter in each column are not significantly different at 0.05 level of significance. *(P value ≤ 0.05).*

This is also in line with Ajay and Shashi (2005) who stated that soil temperature and yield of tomato was significantly improved with mulching over control. The results obtained from the current study proved that groundnut shell and dry guinea grass mulches significantly. White, white-on-black, and aluminized materials constitute the family of reflective mulches. These mulches reflect into the plant canopy most of the incoming solar radiation, and consequently, are more effective in increasing crop yields (Farias-larios *et al.*, 1998).

Since the middle 1980s the use of plastic materials to protect horticultural crops in tunnels and greenhouses is increasing in Southern Brazil. The atmosphere of plastic tunnels and greenhouses presents high values of relative humidity. Soil mulching
reduce soil evaporation and improve in the aerial environment around the plants is expected by its use.

4.1.10 Weight of Non-marketable fruits
The weight of non-marketable fruits showed significant differences between the treatments in both varieties in both seasons (Table 4.2.5). The highest fruit weight was recorded on the control of Cal-J variety. However, during the first season all the treatments were not significantly different from each other apart from that of the sugarcane trash mulch.

Table 4.2.5: Mean weight of non-marketable fruits per plant in plots covered by different mulch types and tomato varieties

<table>
<thead>
<tr>
<th>Variety</th>
<th>Treatment</th>
<th>Season 1</th>
<th>Season 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cal-J</td>
<td>Black Polythene</td>
<td>513a</td>
<td>396a</td>
</tr>
<tr>
<td></td>
<td>No Mulch</td>
<td>661a</td>
<td>417a</td>
</tr>
<tr>
<td></td>
<td>Sugarcane Trash</td>
<td>395b</td>
<td>387a</td>
</tr>
<tr>
<td></td>
<td>White Polythene</td>
<td>540a</td>
<td>378a</td>
</tr>
<tr>
<td>Tylka F1</td>
<td>Black Polythene</td>
<td>517a</td>
<td>381a</td>
</tr>
<tr>
<td></td>
<td>No Mulch</td>
<td>622a</td>
<td>225b</td>
</tr>
<tr>
<td></td>
<td>Sugarcane Trash</td>
<td>612a</td>
<td>224b</td>
</tr>
<tr>
<td></td>
<td>White Polythene</td>
<td>549a</td>
<td>225b</td>
</tr>
<tr>
<td>LSD</td>
<td></td>
<td>194.9</td>
<td>232.2</td>
</tr>
<tr>
<td>P Value</td>
<td></td>
<td>0.039</td>
<td>0.03</td>
</tr>
<tr>
<td>Variety×Treatment</td>
<td></td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

Means followed by the same letter in each column are not significantly different at 0.05 level of significance. *(P value ≤ 0.05).

Soil mulching not only reduces the soil evaporation and weed growth but also improves the aerial environment around the plants which facilitate plant growth and
yield. Polyethylene mulches have induced large increases in growth and yields for a variety of crops, including tomato (Lamont, 1993). These growth and yield increases have been attributed to changes in soil and air temperature near the cover, soil water balance, and nutrient availability compared to non-mulched soil (Haynes, 1987). Less soil compaction and hence improved aeration under mulched soil have also contributed to increased plant growth. Soil temperature can be differentially affected by the type of Polyethylene mulch with temperatures generally following the order: Transparent mulch > Black mulch > White mulch. This is caused primarily through changes in the components of the radiation balance, due to the effect of mulches on albedo, sensible heat flux, latent heat flux, and soil heat flux (Liakatas et al., 1986).

Transparent materials present high transmissivity to solar radiation and thus they are more effective in increasing soil temperature in comparison to the opaque materials, which highly reflect or absorb solar radiation (Rosenberg, 1974). The amount and quality of light intercepted by a crop can be significantly enhanced or modified by the presence of reflecting material on the ground, such as white plastic sheets and mulches. Bare soil reflects 10–20% of the photosynthetic active radiation (PAR) (400–700 nm), whereas white plastic sheets on the soil surface, a common practice in modern greenhouses, may reflect 50–80% of the PAR and increase Pgc over the whole season by at least 7% for an LAI of 3 (Gijzen, 1995). This is especially important for the young crop, where a lot of light is transmitted by the crop and reaches the ground. (Csizinszky, 2005).
4.1.11 Yield
Tomato yield showed significant differences (P value $\leq 0.05$) between varieties and between treatments in the first and second season. Tylika F1 recorded the highest yield per hectare (75.8 t/ha) and (38.35 t/ha) respectively in both seasons (Table 4.2.6) compared to Cal- J variety. Inorganic mulch (white polyethylene film mulch) recorded the highest yield per hectare 79.79 t/ha and 37.14 t/ha respectively compared to organic mulch (sugarcane trash) yield per hectare (50.58 t/ha) and (25.53 t/ha). This study is in conformity with the finding of Li et al. (1995) who reported that plastic film mulching was effective in increasing yield crops. Harmanjeet et al. (2017) reported that plastic mulching influenced higher yield per m2 than non-mulched plots.

Ramakrishna et al. (2006) reported that polythene mulched plots produced the highest yields 94.5 % higher than the un mulched plots in groundnuts. Several other researchers had also reported that mulch provides many benefits to crop production through soil and water conservation which enhanced soil and water conservation, biological activities and improved chemical and physical properties of the soil, and further improve microclimate both beneath and above soil surface which result in faster growth, early canopy development and higher yields (Bakht and khan, 2014, Ogundare et al, 2015, Mukherjee et al., 2010, Singh, 2005, Hedau 1998 and Rahman et al., 2016)
Table 4.2.6: Mean yield kg/m² and t/ha in plots covered by different mulch types and tomato varieties

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Season 1 (Yield kg/m²)</th>
<th>Season 2 (Yield t/ha)</th>
<th>Season 2 (Yield M²)</th>
<th>Season 2 (Yield t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cal J</td>
<td>4.65b</td>
<td>46.5b</td>
<td>2.74b</td>
<td>27.39b</td>
</tr>
<tr>
<td>Tylka F1</td>
<td>7.58a</td>
<td>75.8a</td>
<td>3.83a</td>
<td>38.35a</td>
</tr>
<tr>
<td>LSD</td>
<td>1.44</td>
<td>14.43</td>
<td>0.34</td>
<td>3.42</td>
</tr>
<tr>
<td>No mulch</td>
<td>4.47b</td>
<td>44.73b</td>
<td>2.28c</td>
<td>22.8c</td>
</tr>
<tr>
<td>Black polythene mulch</td>
<td>6.96a</td>
<td>69.55a</td>
<td>2.96b</td>
<td>29.67b</td>
</tr>
<tr>
<td>White polythene mulch</td>
<td>7.97a</td>
<td>79.79a</td>
<td>3.71a</td>
<td>37.14a</td>
</tr>
<tr>
<td>Sugarcane trash mulch</td>
<td>5.05b</td>
<td>50.58a</td>
<td>2.54c</td>
<td>25.53c</td>
</tr>
<tr>
<td>LSD</td>
<td>2.18</td>
<td>21.79</td>
<td>0.28</td>
<td>2.87</td>
</tr>
<tr>
<td>MXV</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

Means followed by the same letter within the same column are not significantly different at 0.05 level of significance. *(P value ≤ 0.05). V - Tomato varieties, M- mulching type.

The effects of various mulches on soil microclimate recently have been reviewed by Streck et al. (1994). In this review the authors demonstrated that opaque mulches (black, white and coloured plastics, paper, petroleum, bitumen, and straw) decrease the soil heat flux and the daily amplitude of the soil temperature. Transparent and translucent mulches promote a relatively large net radiation at the soil surface, increase soil heat flux and, consequently, the minimum and maximum soil temperature is increased. Lamont, (1993) reviewed other aspects of plastic mulch as specifications, importance of colour, and its advantages and disadvantages. The colour of mulch determines its energy-radiating behaviour and its influence on the microclimate around the plant. Black, transparent, and white mulches predominate in the commercial vegetable production today over the world (Lamont, 1993). White mulch has been replaced largely by a co-extruded white-on-black. In the second
season, the same trend as that of the first season was observed with Tylka F1 variety out yielding the other variety on the white polythene mulch with a mean of 33.2 tonnes per hectare while the lowest observed on the control where no mulch was applied (Table 4.2.6).

The highest tomato yield obtained is associated with profound root growth for maximum interception of water and nutrient absorption in the soil under mulching materials. Moorby and graves (1998) Associated greater growth to large leaf area and total dry matter production, increased length of root system and hence absorption of larger amounts of plant nutrients. Taber and smith (2009) and Lamonte (1999) associated significant influence of organic and inorganic mulch over control to rise in root temperature by inorganic mulch materials which results in increased growth and subsequent yield.

4.2 Effect of mulching on incidences of tomato pests
4.2.1 Weed fresh and dry weight
The weed fresh and dry weights were significantly influenced by the application of mulching treatments in both seasons. During the first season, the highest fresh and dry weight of weeds was observed on the control plots where Cal-J variety had the highest (522 g) and on Tylka F1 (436 g) in a metre quadrat (Table 4.3.1 and 4.3.2). The dry weight of the weeds also remained highest in the two treatments while the lowest was recorded under the black polythene mulch for the fresh and dry weights.
Table 4.3.1: Mean weed fresh and dry weight in plots covered by different mulch types and tomato varieties

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Season 1</th>
<th>Season 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WFW</td>
<td>WDW</td>
</tr>
<tr>
<td>Cal –J</td>
<td>153.0a</td>
<td>10.70a</td>
</tr>
<tr>
<td>Tylika F1</td>
<td>138.0a</td>
<td>9.60a</td>
</tr>
<tr>
<td><strong>LSD</strong></td>
<td><strong>188.4</strong></td>
<td><strong>13.9</strong></td>
</tr>
<tr>
<td>No mulch</td>
<td>479.2a</td>
<td>33.54a</td>
</tr>
<tr>
<td>Black polythene mulch</td>
<td>3.5b</td>
<td>0.25b</td>
</tr>
<tr>
<td>White polythene mulch</td>
<td>35.7b</td>
<td>2.50b</td>
</tr>
<tr>
<td>Sugarcane trash mulch</td>
<td>63.7b</td>
<td>4.46b</td>
</tr>
<tr>
<td><strong>LSD</strong></td>
<td><strong>80.2</strong></td>
<td><strong>5.61</strong></td>
</tr>
<tr>
<td>MXV</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

Means followed by the same letter within the same column are not significantly different at 0.05 level of significance. *(P value ≤ 0.05), NS (P value > 0.05)*.

WFW- weeds fresh weight, WDW-weed dry weight, V- tomato varieties, M- mulching type.
Table 4.3.2: Interactions effect on mulching types and tomato varieties on weed fresh and dry weight in season 1

<table>
<thead>
<tr>
<th>Treatments</th>
<th>WFW</th>
<th>WDW</th>
</tr>
</thead>
<tbody>
<tr>
<td>WPCalJ</td>
<td>30.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.10&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>CntrCalJ</td>
<td>522.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36.54&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>STCalJ</td>
<td>57.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.92&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>BPCalJ</td>
<td>4.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.28&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>CntrlTYlkaF1</td>
<td>436.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30.54&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>STTylkaF1</td>
<td>70.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.92&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>WPTylkaF1</td>
<td>41.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.89&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>BPTylkaF1</td>
<td>3.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.21&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>LSD</td>
<td>121.4</td>
<td>8.45</td>
</tr>
</tbody>
</table>

Means followed by the same letter within the same column are not significantly different at 0.05 level of significance. *(P value ≤ 0.05). WFW- weeds fresh weight, WDW- weed dry weight control CAL J-(no mulch), WPCALJ(white polythene mulch CAL J), BPCALJ(black polythene mulch CAL J), STCAL J(sugarcane trash mulch CAL J), control TYLKA F1-(no mulch), WP TYLKA F1(white polythene mulch TYLKA F1), BP TYLKA F1 (black polythene mulch TYLKA F1), ST TYLKA F1( sugarcane trash mulch TYLKA F1).
Table 4.3.3: Weed fresh and dry weight at Mabanga ATC under different mulching treatments during the first season

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Variety</th>
<th>Wet Weed weight</th>
<th>Dry Weed weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Polythene Mulch</td>
<td>Cal-J</td>
<td>4&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.3&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>No Mulch Sugarcane Trash Mulch</td>
<td>Cal-J</td>
<td>522&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36.5&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>White Polythene Mulch</td>
<td>Cal-J</td>
<td>57&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.0&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Black Polythene Mulch</td>
<td>Cal-J</td>
<td>30&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.1&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>No Mulch Sugarcane Trash Mulch</td>
<td>Tylka F1</td>
<td>3&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.2&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>White Polythene Mulch</td>
<td>Tylka F1</td>
<td>436&lt;sup&gt;b&lt;/sup&gt;</td>
<td>30.5&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>No Mulch Sugarcane Trash Mulch</td>
<td>Tylka F1</td>
<td>70&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.9&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>White Polythene Mulch</td>
<td>Tylka F1</td>
<td>41&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.0&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

SE 57.1 3.995
P Value <.001 <.001
Variety×Treatment  *

Means followed by the same letter in each column are not significantly different at 0.05 level of significance. *(P value ≤ 0.05).

Besides diseases and insect pests, weeds are a major contributor to overall losses and problem in its cultivation. The first 3-6 weeks after transplanting is the critical period for weed competition in tomato cultivation and unrestricted weed competition may reduce tomato fruit yield by 40-60 % (Adigun, 2005). Various workers have reported the beneficial effect of both organic mulches viz., straw and inorganic mulches viz., polyethylene mulches on growth and yield parameters in tomato and alteration in the hydrothermal regime of the crops and suppression of weed growth.
Polyethylene mulches are widely used in vegetable production and have contributed significantly to reduction of losses due to weed competition (Uguajio and Ernest, 2004). Film colour may affect effective weed seed germination, growth, and development under the plastic (Brault et al. 2002). Black polyethylene plastic mulch is the standard plastic mulch used in vegetable production (Gordon et al., 2010). Researchers using black plastic instead of bare soil have recorded higher yields (Mirshekari et al. 2012); Ragablarigani and Aghaalkhani, (2011), earlier harvests Ihara et al. (2010), Lamont (1993). Earlier, Sweeney et al. (1987) and Bhella (1988) have also reported the moisture-conserving property of polyethylene mulches. Ability of organic mulch to conserve soil moisture was appreciably lower than that of the polyethylene mulch (Chakraborty and Sadhu, 1994). The natural mulching (paddy-straw or sugarcane trash) also stimulated vegetative growth compared to un-mulched but to a lesser extent than polyethylene mulch. Different mulch materials influenced flowering and fruiting in tomato (Decoteau et al., 1986). The natural mulching materials such as paddy-straw or sugarcane trash retarded the weed growth considerably compared to control (Kwon et al., 1988).

In the second season, the same trend of the first season was replicated where the controls had the highest fresh and dry weight of the weed mass from a metre quadrat (Table 4.3.4). The black polythene mulch had the highest suppression index of the weeds for the fresh and dry weight.
Table 4.3.4: Weed fresh and dry weight at Mabanga ATC under different mulching treatments during the second season

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Variety</th>
<th>Wet Weed weight</th>
<th>Dry Weed weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Polythene Mulch</td>
<td>Cal-J</td>
<td>3c</td>
<td>0.2c</td>
</tr>
<tr>
<td>No Mulch</td>
<td>Cal-J</td>
<td>288a</td>
<td>23.0a</td>
</tr>
<tr>
<td>Sugarcane Trash Mulch</td>
<td>Cal-J</td>
<td>27b</td>
<td>2.2b</td>
</tr>
<tr>
<td>White Polythene Mulch</td>
<td>Cal-J</td>
<td>17b</td>
<td>1.4b</td>
</tr>
<tr>
<td>Black Polythene Mulch</td>
<td>Tylka F1</td>
<td>2c</td>
<td>0.2c</td>
</tr>
<tr>
<td>No Mulch</td>
<td>Tylka F1</td>
<td>301a</td>
<td>24.1a</td>
</tr>
<tr>
<td>Sugarcane Trash Mulch</td>
<td>Tylka F1</td>
<td>30b</td>
<td>2.4b</td>
</tr>
<tr>
<td>White Polythene Mulch</td>
<td>Tylka F1</td>
<td>38b</td>
<td>3.0b</td>
</tr>
<tr>
<td>SE</td>
<td>10.13</td>
<td></td>
<td>0.81</td>
</tr>
<tr>
<td>P Value</td>
<td>&lt;.001</td>
<td></td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Variety×Treatment</td>
<td>*</td>
<td></td>
<td>*</td>
</tr>
</tbody>
</table>

Means followed by the same letter in each column are not significantly different at 0.05 level of significance. *(P value ≤ 0.05).

The results indicated that organic mulch application in both rainy and dry seasons significantly influenced soil temperature and suppressed weed growth. According to Dilipkumar et al. (1990), organic mulching reduces weed infestation and enhances growth and yield of crops. Increase in yield because of reduced crop-weed competition due to weed suppression by organic mulching has been reported by several workers (Roe et al., 1993; Unger, 1995; Hendrickson, 1997; Schonbeck and Evanylo, 1998).

Mintah (1998), also reported that Mucuna pruriens mulched plots recorded the lowest weed population than the no mulch plots. According to Nkansah et al. (2003), grass straw, rice straw, rice husk and saw dust mulches significantly reduced
fresh weed weight. They also stated that grass straw mulch significantly reduced fresh weed weight while the highest fresh weed weight was observed in the control. According to Norman et al. (2011) dry grass and sawdust mulches suppressed weed growth significantly.

4.2.2 Bacterial wilt incidences
The influence of the mulching treatments on the incidences of bacterial wilt was not significant in both seasons on the two tomato varieties (Table 4.4). However, the incidence rate was higher during the second season compared to the first season with the highest incidence recorded on the white polythene mulch treatment at (23%) in the second season under Cal-J variety while the lowest incidence was recorded on the black polythene mulch of Tylka F1 variety at (2%) (Appendix 1).

The influence of the mulching treatments on the incidences of bacterial wilt was not significant in both seasons (Table 4.4). However, the incidence rate was higher during the second season compared to the first season with the highest recorded on the no mulch treatment (18.8%) in the second season while on the varieties Cal-J variety had the highest (19.5%) during the second season. The black mulch treatment had the lowest bacterial wilt incidences percentage in both seasons as well as Tylka F1 variety.

The application of black polythene mulch reduced the incidences of bacterial wilt though not significantly therefore indicating the importance of integrated disease management practices where this mulch practice can be combined with others. Where the effects of the mulching materials are marginal in relation to disease
control, the factors which improve its efficiency, such as maintaining adequate moisture levels increasing the treatment time assumes more importance (Pullman et al., 1979). Soil treatments, including modification of soil pH, solarization and application of stable bleaching powder reduced bacterial populations and disease severity on a small scale (Saddler, 2005) and therefore consistent use of mulching can be a solution as the soil temperature is controlled to a certain degree desired by the farmer.

Table 4.4: Bacterial wilt incidences (%) in Plots mulched by different materials during the first and second season at Mabanga ATC

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Season 1</th>
<th>Season 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Polythene Mulch</td>
<td>1.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.8&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>No Mulch</td>
<td>5.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.8&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sugarcane Trash Mulch</td>
<td>2.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>16.7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>White Polythene Mulch</td>
<td>1.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.5&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>SED</td>
<td>2.826</td>
<td>14.01</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.492</td>
<td>0.902</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variety</th>
<th>Season 1</th>
<th>Season 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cal-J</td>
<td>2.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.5&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tylka F1</td>
<td>1.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9.4&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>SED</td>
<td>0.712</td>
<td>4.17</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.332</td>
<td>0.137</td>
</tr>
<tr>
<td>T×V</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

Means followed by the same letter in each column are not significantly different at 0.05 level of significance. *(P value ≤ 0.05).

The low incidence levels of bacterial wilt observed in plots covered with mulch, might have been as a result of soil thermal modification this suggestion is supported (Katan, 1976) who found that soil Solarization using transparent plastic mulches for 60 days prior to the planting of tomatoes reduced the incidence of bacterial wilt. Another study reported Baptista et al. (2006) studied the mechanisms of soil solarization that reduced bacterial wilt in the tomato. A heat treatment at either 45°C
for 2 days or a minimum temperature of 60°C for 2 hours of the infected soil prior to tomato planting reduced the total bacterial population.

4.2.3 Effect of organic and inorganic mulching on Physiological Disorders Presence (BER)

The presence of physiological disorders in the two tomato varieties was not significantly influenced by the mulching materials in both seasons (Table 4.5). However, variety Cal-J had higher physiological disorders incidences for both seasons with 6.3% during the first season and 5.9% during the second season which was marginally higher than that of Tylka F1. Among the treatments, no mulch had the highest physiological disorder incidences for both seasons with the highest (6.7%) recorded during the first season.

The presence of physiological disorders particularly blossom end rot in the two tomato varieties was not significantly influenced by the mulching materials in both seasons (Table 4.5). However, the highest incidences were observed in Tylka variety not mulched at 6.7% in the second season. Despite the minimal differences it can be observed that there were more incidences of blossom end rot in Tylka variety than Cal J variety. Its further observed in this study that the incidence of blossom end rot were higher in control treatment followed by sugarcane treatment.

This study agrees with several other researchers who observed that susceptibility to blossom end rot varies among tomato varieties and is associated with soil moisture content (Steven, 1986; Shaykewich, 1971; Hagassou et al., 2019; Syengo et al., 2019). Tylka F1 variety showed high susceptibility to blossom end rot compared
with Cal J variety under low moisture content. The susceptibility to blossom end rot can be associated to the growing habit and pruning with reduces canopy cover of the soil exposing the soil to moisture losses through evaporation and transpiration. Growing Tylka variety in open field condition during the short rain season Bungoma will require mulching and supplementary irrigation to reduce losses due to blossom end rot.

This study does not confirm what other researchers found out relating mulching to reduced incidences of blossom end rot. Elmer and Ferrandino, 1991; John et al. 2005; Magnusson, 2002 concluded that organic mulches decrease the incidence of Calcium deficiency in plants by maintaining adequate soil moisture throughout the season and thereby helps to reduce BER (Appendix 2).

Table 4.5: Mulching treatment effect on the physiological disorder Incidences BER (%) at Mabanga ATC during the first and second seasons

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Season 1</th>
<th>Season 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Polythene Mulch</td>
<td>4.0a</td>
<td>4.8a</td>
</tr>
<tr>
<td>No Mulch</td>
<td>6.7a</td>
<td>6.2a</td>
</tr>
<tr>
<td>Sugarcane Trash Mulch</td>
<td>6.3a</td>
<td>5.7a</td>
</tr>
<tr>
<td>White Polythene Mulch</td>
<td>4.7a</td>
<td>5.2a</td>
</tr>
<tr>
<td><strong>SED</strong></td>
<td><strong>2.032</strong></td>
<td><strong>1.435</strong></td>
</tr>
<tr>
<td><strong>P-Value</strong></td>
<td><strong>0.516</strong></td>
<td><strong>0.829</strong></td>
</tr>
<tr>
<td><strong>Variety</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cal-J</td>
<td>6.3a</td>
<td>5.9a</td>
</tr>
<tr>
<td>Tylka F1</td>
<td>4.5a</td>
<td>5.2a</td>
</tr>
<tr>
<td><strong>SED</strong></td>
<td><strong>0.682</strong></td>
<td><strong>0.25</strong></td>
</tr>
<tr>
<td><strong>P-Value</strong></td>
<td><strong>0.115</strong></td>
<td><strong>0.095</strong></td>
</tr>
<tr>
<td><strong>T×V</strong></td>
<td><strong>NS</strong></td>
<td><strong>NS</strong></td>
</tr>
</tbody>
</table>

Means followed by the same letter in each column are not significantly different at 0.05 level of significance. *(P value ≤ 0.05), NS (P value > 0.05).*
4.3 Influence of organic and inorganic mulching materials on the soil moisture

Significant differences were observed on the soil moisture content due to mulching treatments under two tomato varieties. In the first season, the highest soil moisture content was recorded on the black (22.1) and white polythene mulches (20.6) from 2 weeks after transplanting (WAT) to 10 weeks after transplanting (WAT) (Figure 4.3 and Table 4.6.1). The lowest soil moisture was recorded under the no mulch treatments (7.0) in both varieties from 2 (WAT) to 10 (WAT) (Appendix 3).
Figure 4.3 Influence of mulching treatments on the soil moisture during the first season from week 2 after transplanting (WAP) to week 10 after transplanting
Table 4.6.1: Soil moisture content (%) in plots covered by different mulch during the first season

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Variety</th>
<th>2 WAT</th>
<th>4 WAT</th>
<th>6 WAT</th>
<th>8 WAT</th>
<th>10 WAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Polythene</td>
<td>Cal-J</td>
<td>17.4\textsuperscript{a}</td>
<td>18.6\textsuperscript{a}</td>
<td>18.3\textsuperscript{a}</td>
<td>21.0\textsuperscript{a}</td>
<td>16.7\textsuperscript{b}</td>
</tr>
<tr>
<td>No Mulch Sugarcane</td>
<td>Cal-J</td>
<td>8.8\textsuperscript{b}</td>
<td>11.4\textsuperscript{b}</td>
<td>10.2\textsuperscript{b}</td>
<td>11.4\textsuperscript{a}</td>
<td>12.3\textsuperscript{d}</td>
</tr>
<tr>
<td>White Mulch</td>
<td>Cal-J</td>
<td>15.5\textsuperscript{a}</td>
<td>15.0\textsuperscript{b}</td>
<td>17.5\textsuperscript{a}</td>
<td>18.9\textsuperscript{a}</td>
<td>15.0\textsuperscript{b}</td>
</tr>
<tr>
<td>Black Polythene</td>
<td>Cal-J</td>
<td>17.3\textsuperscript{a}</td>
<td>20.4\textsuperscript{a}</td>
<td>20.6\textsuperscript{a}</td>
<td>20.4\textsuperscript{a}</td>
<td>20.0\textsuperscript{a}</td>
</tr>
<tr>
<td>No Mulch Sugarcane</td>
<td>Tylka F1</td>
<td>14.3\textsuperscript{a}</td>
<td>19.2\textsuperscript{a}</td>
<td>20.7\textsuperscript{a}</td>
<td>22.1\textsuperscript{a}</td>
<td>20.2\textsuperscript{a}</td>
</tr>
<tr>
<td>White Mulch</td>
<td>Tylka F1</td>
<td>7\textsuperscript{b}</td>
<td>12.6\textsuperscript{b}</td>
<td>9.9\textsuperscript{b}</td>
<td>11.9\textsuperscript{b}</td>
<td>12.1\textsuperscript{d}</td>
</tr>
<tr>
<td>Black Polythene</td>
<td>Tylka F1</td>
<td>14.5\textsuperscript{a}</td>
<td>13.9\textsuperscript{b}</td>
<td>20.1\textsuperscript{a}</td>
<td>19.3\textsuperscript{a}</td>
<td>14.5\textsuperscript{d}</td>
</tr>
<tr>
<td>No Mulch Sugarcane</td>
<td>Tylka F1</td>
<td>16.7\textsuperscript{a}</td>
<td>19.3\textsuperscript{a}</td>
<td>18.5\textsuperscript{a}</td>
<td>19.1\textsuperscript{a}</td>
<td>17.6\textsuperscript{b}</td>
</tr>
</tbody>
</table>

LSD                  | 1.849      | 1.729  | 2.301  | 1.78   | 1.347  |

P Value               | <0.001     | <0.001 | <0.001 | <0.001 | 0.045  |

Means followed by the same letter in each column are not significantly different at 0.05 level of significance. *(P value ≤ 0.05), WAT-Weeks after transplanting.

The highest soil moisture was recorded in the plots mulched with Plastic film because plastic film forms a barrier preventing soil moisture to escape (Appendix 3). Water that evaporates from the soil surface under plastic mulch film, condenses on the lower surface of the film and falls back as droplets. Thus, moisture is preserved for several days as compared with organic mulching material and no mulch which allows evaporation to the atmosphere. It is evident that mulching conserves moisture in the root zone of the crop reducing moisture stress over the growing season of the tomato crop. Reduction of water stress and water deficit in the
soil enhances most physiological processes since water is a transporting agent and a reactant in many metabolic reactions.

Tomatoes are overly sensitive to water deficits during and immediately after transplanting, at flowering and during fruit development (Doorenbos and Kassam, 1979). Nyabundi and Hsiao, 1989a) reported that when tomato plants are subjected to different levels of water stress under field conditions, vegetative growth was inhibited but flower retention and fruit development were enhanced and lead to early fruit ripening (Nyabundi and Hsiao, 1989b). It has been reported that water deficit stress increases the flower abortion, thus affects the fruits settings. It was observed that only 50% of the flowers produced developed into fruits, thus sink size was a limiting factor to fruit production in tomato (Olaniyi, 2010)

The conserved moisture due to mulch treatments had a positive role in tomato growth and development as compared to no mulch plots. Mulched plots showed high growth and reproductive parameters compared to no mulch plots. The soil moisture conserved by the mulching treatment was vital for initiation and differentiation of vegetation and reproductive primordial in the epical meristem and enlargement of cells, nutrient flow, protein and carbohydrate synthesis and metabolism. The lowest soil moisture conserved by bare plots was responsible for poor growth and reproductive performance. Under water deficit conditions due moisture loss through transpiration and evaporation plants tend to suspend cell division and primordial initiation impairing subsequent vegetative and floral development. Several laboratory and field studies have demonstrated that the
presence of a mulch on the soil surface increases soil water content (Jones et al., 1969; Blevins et al., 1971; Greb et al., 1967; Unger, 1978; Steiner, 1989) and decreases soil temperature in relation to a bare soil (Gupta et al., 1983; Ghosh et al., 2006).

During the second season the highest soil moisture content was recorded in plots mulched with white polythene film (19.3) and black polythene film (18.6) from 2 WAT to 10 WAT while the lowest was on the control treatment (6.2) (Table 4.6.2). The rate of water loss from around the crop and from the crop through transpiration and evaporation is determined by the amount of energy received by the plant canopy and air flow. The surfaces of mulched plots and bare soil absorbed solar radiation differently. Mulched surfaces decreased the thermal admittance of the surface relative to that of bare soil, so that more of the absorbed radiant heat goes to the atmosphere, thus decreasing the energy available to heat the soil. Soil warming is also affected the rate of evaporation under a mulch relative to a bare soil (Hsiao, 1986).
Table 4.6.2: Soil moisture content (%) in plots covered by different mulch during the second season

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Variety</th>
<th>2 WAT</th>
<th>4 WAT</th>
<th>6 WAT</th>
<th>8 WAT</th>
<th>10 WAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Polythene Mulch</td>
<td>Cal-J</td>
<td>17.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>No Mulch Sugarcane Trash</td>
<td>Cal-J</td>
<td>8.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9.3&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>9.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>8.9&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>White Polythene Mulch</td>
<td>Cal-J</td>
<td>12.9&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>15.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.4&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Black Polythene Mulch</td>
<td>Cal-J</td>
<td>14.8&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>16.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.3&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tylka F1 Mulch</td>
<td>Tylka F1</td>
<td>16.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>17.1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>No Mulch Sugarcane Trash</td>
<td>Tylka F1</td>
<td>8.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>8.5&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>White Polythene Mulch</td>
<td>Tylka F1</td>
<td>13.3&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>15.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15.0&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>13.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.3&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tylka F1 Mulch</td>
<td>Tylka F1</td>
<td>15.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

LSD 1.649  2.679  1.919  1.178  1.841
P Value <.001  0.002  <.001  <.001  <.001
Variety X Treatment *  *  *  *  *

Means followed by the same letter in each column are not significantly different at 0.05 level of significance. *(P value ≤ 0.05), WAT-Weeks after transplanting.

This study is in agreement with other studies conducted by several studies conducted by (Fraedrich and Ham, 1982; Unger, 1995; Agele et al., 2000) have shown that mulching with organic materials conserved soil moisture and consequently increased crop production. According to Dilipkumar et al. (1990), mulching reduces soil water evaporation enhancing more retention of soil moisture. Moisture retention of soil has been shown to be improved by the application of inorganic and organic mulches.

Higher soil moisture was observed in plot with polyethylene mulch when compared with plots with organic mulch and the control (Table 4.6.2), the result is in line with
the finding of Sweeney et al. (1987), they reported the moisture conserving property of polyethylene mulches were higher followed by Organic mulches (maize straw, palm fronts and grasses) which recorded slightly higher soil moisture than the control. Chakraborty and sadhu (1994) and Singh (2005) also reported the ability of organic mulch to conserve soil moisture was appreciably lower than that of the polyethylene mulch. Plot with no mulch recorded least moisture content in this experiment. The result is in line with the finding of Bhella (1988). No stick staking plots had higher soil moisture content than stick staking plots. The observed higher moisture recorded in no stick staking plots could be due to the foliage of tomato that spread on the soil and acted like cover crop, thereby reduces the rate of soil evaporation.

4.4 Relationship of soil moisture, weeds and tomato productivity parameter in

4.4.1 Relationship of soil moisture, weeds and tomato productivity parameters in season1

In Cal J tomato variety, the relationship of soil moisture increase was negative to the total biomass ($r = -0.49$), weed dry weight ($r = -0.47$) and the total yields ($r = -0.46$). The relationship of the moisture increase to Blossom end rot (BER) incidences in this variety was positive ($r = 0.50$). Similarly, the relationship of total Biomass was strongly positive with the total yields and the weed dry weight ($r = 1$ and 1, respectively) (Figure 4.4.1).
Figure 4.4.1: Correlation matrix of soil moisture, weeds and tomato productivity for Cal J tomato variety under no mulch in season 1. *(P value ≤ 0.05).

Under sugarcane trash mulch, Cal J tomato variety displayed a negative relationship of soil moisture increase with BER incidences (r = -0.32). However, the relationship of soil moisture increase was positive to the total biomass (r = 0.80), weed dry weight (r = 0.57) and the total yields (r = 0.80). Similarly, the relationship of total Biomass was strongly positive with the total yields (r = 1) (Figure 4.4.2).
Figure 4.4.2: Correlation matrix of soil moisture, weeds and tomato productivity for Cal J tomato variety under sugarcane trash mulch in season 1. ***(P value ≤ 0.001).***

Under black polyethene mulch, Cal J tomato variety displayed a negative relationship of soil moisture increase with the total biomass \( r = -0.90 \), weed dry weight \( r = -0.95 \) and yields \( r = -0.89 \). However, there was a weak positive relationship of increase in soil moisture with BER incidences \( r = 0.032 \). The relationship of the total biomass was positive to the weed dry weight \( r = 0.73 \), and the total yields \( r = 1 \) (Figure 4.4.3).
Figure 4.4.3: Correlation matrix of soil moisture, weeds and tomato productivity for Cal J tomato variety under black polythene mulch in season 1. *(P value ≤ 0.05).

Under white polyethene mulch, Cal J tomato variety displayed a negative relationship of soil moisture increase with the total biomass (r = -0.92), weed dry weight (r = -0.51) and yields (r = 0.85). However, there was a positive relationship of increase in soil moisture with BER incidences (r = 0.34). The relationship of the total biomass was positive to the weed dry weight (r = 0.81), and the total yields (r = 0.99) (Figure 4.4.4).
In Tylka F1 tomato variety, the relationship of soil moisture increase was negative to the total biomass ($r = -0.80$) and the total yields ($r = -0.80$). The relationship of the moisture increase was positive to the weed dry weight ($r = 0.87$) Blossom end rot (BER) incidences ($r = 0.30$). Similarly, the relationship of total biomass was strongly positive with the total yields ($r = 1.00$), but strongly negative with the weed dry weight ($r = -0.99$) and BER incidences ($r = -0.82$) (Figure 4.4.5).
Figure 4.4.5: Correlation matrix of soil moisture, weeds and tomato productivity for Tylka F1 tomato variety under no mulch in season 1. **(P value ≤ 0.01).

Under sugarcane trash mulch, Tylka F1 tomato variety displayed a negative relationship of soil moisture increase to total biomass (r = -0.49), weed dry weight (r = -0.72) and total yields (r = -0.52). BER incidences (r = -0.32). However, the relationship of soil moisture increase was positive to the total biomass (r = 0.80), weed dry weight (r = 0.57) and the total yields (r = 0.80). Similarly, the relationship of total biomass was strongly positive with the total yields (r = 1) (Figure 4.4.6).
Figure 4.4.6: Correlation matrix of soil moisture, weeds and tomato productivity for Tylka F1 tomato variety under sugarcane trash mulch in season 1. *(P value ≤ 0.05).

Under black polyethylene mulch, Tylka F1 tomato variety displayed a negative relationship of soil moisture increase with the total biomass (r = -0.59) and yields (r = -0.56). However, there was a positive relationship of increase in soil moisture with weed dry weight (r = 0.42) and BER incidences (r = 0.58). The relationship of the total biomass was positive to the weed dry weight (r = 0.49), and the total yields (r = 1) (Figure 4.4.7).
Figure 4.4.7: Correlation matrix of soil moisture, weeds and tomato productivity for Tylka F1 tomato variety under black polythene mulch in season 1. *(P value ≤ 0.05), ***(P value ≤ 0.01).

Under white polyethylene mulch, Tylka F1 tomato variety displayed a negative relationship of soil moisture increase with the total biomass \((r = -0.68)\), weed dry and yields \((r = -0.63)\). There was a positive relationship of increase in soil moisture with weed dry weight \((r = 0.82)\) and BER incidences \((r = 0.67)\). The relationship of the total biomass was negative to the weed dry weight \((r = -0.15)\), but there was a strong positive relationship of total biomass with the total yields \((r = 1)\) (Figure 4.4.8).
4.4.2 Relationship of soil moisture, weeds and tomato productivity parameter in season 2

In Cal J tomato variety, the relationship of soil moisture increase was negative to the weed dry weight ($r = -0.78$) and BER ($r = -0.12$). The relationship of the moisture increase was positive to the total biomass ($r = 0.48$) and total yields ($r = 1$). Similarly, the relationship of total Biomass was strongly positive with the total yields ($r = 1$) and the weed dry weight ($r = 1$) (Figure 4.5.1).
Figure 4.5.1: Correlation matrix of soil moisture, weeds and tomato productivity for Cal J tomato variety under no mulch in season 2. **(P value ≤ 0.01).

Under sugarcane trash mulch, Cal J tomato variety displayed a negative relationship of soil moisture increase with the weed dry weight ($r = -0.88$) and BER incidences ($r = -0.98$). On the other hand, there was a weak negative relationship of the increase in soil moisture with the total biomass ($r = -0.047$) and total yields ($r = -0.067$). The relationship of total Biomass was negative to the weed dry weight ($r = -0.44$), but strongly positive with the total yields ($r = 1$) (Figure 4.5.2).
Figure 4.5.2: Correlation matrix of soil moisture, weeds and tomato productivity for Cal J tomato variety under sugarcane trash mulch in season 2. *(P value ≤ 0.05).*

Under black polyethylene mulch, Cal J tomato variety displayed a negative relationship of soil moisture increase with the weed dry weight ($r = -0.90$), however, the relationship of soil moisture increase with the total biomass ($r = 0.43$), BER (0.22) and the total yields ($r = 0.52$). The relationship of the total biomass was positive to the weed dry weight ($r = 0.38$), and the total yields ($r = 0.99$) (Figure 4.5.3).
Figure 4.5.3: Correlation matrix of soil moisture, weeds and tomato productivity for Cal J tomato variety under black polythene mulch in season 2

Under white polyethene mulch, Cal J tomato variety displayed a negative relationship of soil moisture increase with the total biomass ($r = -0.92$), weed dry weight ($r = -0.51$) and yields ($r = -0.85$). However, there was a negative relationship of increase in soil moisture with BER incidences ($r = -1.0$). The relationship of the total biomass was positive to the weed dry weight ($r = 0.81$), and the total yields ($r = 0.99$) (Figure 4.5.4).
Figure 4.5.4: Correlation matrix of soil moisture, weeds and tomato productivity for Cal J tomato variety under white polythene mulch in season 2. *(P value ≤ 0.05).

In Tylka F1 tomato variety, the relationship of soil moisture increase was positive to the total biomass (r = 1), weed dry weight (r = 0.77), and the total yields (r = 1). Similarly, the relationship of total biomass was strongly positive with the total yields (r = 1.00) and weed dry weight (r = 0.76) (Figure 4.5.5).
Figure 4.5.5: Correlation matrix of soil moisture, weeds and tomato productivity for Tylka F1 tomato variety under no mulch in season 2. *(P value ≤ 0.05), **(P value ≤ 0.01).

Under sugarcane trash mulch, Tylka F1 tomato variety displayed a negative relationship of soil moisture increase to total biomass ($r = -0.23$) and total yields ($r = -0.34$). The relationship of soil moisture increase was positive with weed dry weight ($r = 0.61$) and BER incidences ($r = 0.84$). Similarly, the relationship of total biomass was positive to the weed dry weight ($r = 0.62$) and the total yields ($r = 0.99$) (Figure 4.5.6).
Figure 4.5.6: Correlation matrix of soil moisture, weeds and tomato productivity for Tylka F1 tomato variety under sugarcane trash mulch in season 2

Under black polyethene mulch, Tylka F1 tomato variety displayed a positive relationship of soil moisture increase with the total biomass ($r = 0.081$), weed dry weight ($r = 0.12$), BER (0.60) and yields ($r = 0.079$). The relationship of the total biomass was negative to the weed dry weight ($r = -0.98$) but had a strong positive relationship with the total yields ($r = 1$) (Figure 4.5.7).
Figure 4.5.7: Correlation matrix of soil moisture, weeds and tomato productivity for Tylka F1 tomato variety under black polythene mulch in season 2. ***(P value ≤ 0.01).***

Under white polyethene mulch, Tylka F1 tomato variety displayed a negative relationship of soil moisture increase with the total biomass (r = - 0.94), weed dry weight (r = -0.51), and total yields (r = - 0.51). There was a positive relationship of increase in soil moisture with BER incidences (r = 0.31). The relationship of the total biomass was positive to the weed dry weight (r = 0.78) and the total yields (r = 0.99) (Figure 4.5.8).
In general, the relationship of the moisture level, weeds and yield parameters of two tomato varieties observed under different mulching materials in figures 4.5.1 to 4.5.8, indicate that, with mulching there could have been some enhanced conservation of soil moisture which may have positively influenced the total biomass as well as tomato yields. In most instances under mulch, total biomass increase had poor correlation with weed dry weight indicating smothering of weeds, this is normally expected under mulch and agrees with several other reports by Jabran, (2019) and Ferdous et al., (2017). Furthermore The increase in moisture conservation in under mulching materials appeared to have a week positive correlation or a strong negative correlation with the blossom end rot incidences (expect Tylka F1) this indicates moisture conservation by the mulch reduces blossom end rot physiological disorder this agrees with Gebremariam and Tesfay, (2019) and Tembe et al. (2017), however
it also indicates that Tylka F1 variety has high demand for Calcium compared to Cal J variety.
CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion
i. Inorganic mulch led to the highest number of branches per plant, number of trusses per plant, number of open flowers, Shoot mass and plant height of both Cal-J and Tylka F1 varieties. The highest number of large fruits was recorded in CalJ variety while the highest yield was recorded in Tylka F1 variety for both seasons where inorganic mulch was used.

ii. Weeds growth was significantly suppressed under the different mulches with the highest observed in inorganic mulch. The different mulching treatments did not have significant influence on the bacterial wilt and physiological disorders incidences for both seasons.

iii. Inorganic mulch was superior to organic mulch in conserving soil moisture.

5.2 Recommendations
i. In their effects on growth and yield, the white and black plastic mulches are recommended as a crop husbandry practice to farmers. Use of Tylka F1 variety under these mulches is highly encouraged to achieving the highest yields.

ii. Black polythene mulch is recommended for the control of weeds however organic mulching materials can also be used by farmers based on availability, keeping in mind their performance compared to the control led to better crop growth and least weed development.

iii. The black polythene mulch is recommended for higher soil moisture retention in tomato production.
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APPENDICES

Appendix 1: Bacterial wilt incidences in the tomato plants during the study

A- Bacterial wilt incidences in Tylka F1 variety in season 1

B- Bacterial wilt incidences in Tylka F1 variety in season 2
Appendix 2: Blossom end rot incidences in the tomato varieties during the study

A- Blossom end rot incidences in Tylka variety in season 2

B- Blossom end rot incidences in Cal J variety in season 2
Appendix 3: Condensing water trapped by plastic films