Growth, yield and quality response of beetroot to organic mulches in tropical conditions.

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Abstract

A field experiment was conducted in Malawi (Bvumbwe, Thyolo) between June and September 2020 to evaluate the impact of locally found organic mulches, viz maize straw (SM) and compost mulches (CM), with an un-mulched control, on the growth, yield and quality of three beetroot varieties, viz Detroit dark red (DDR), Crimson globe (CG) and Globe dark red (GDR). The experiment was set up under a split-plot design, randomized, and replicated three times. During the experiment, observations on plant height, number of leaves, leaf length and width, marketable and non-marketable yield, root diameter, shoot and root dry weights and dry matter content were recorded. The profitability of the two mulch treatments was assessed by working out the net profit for each treatment per hectare. The results showed that mulching improved all growth parameters and yield in beets. Additionally, net return was maximized by mulching. Compost mulch produced superior results with the highest plant height (20.6cm) and marketable yield (2423g) while the control had the least plant height (12.7cm) and marketable yield (443g) which subsequently reduced the overall net profit. However, mulching did not affect dry matter percentage as there were no significant differences observed between the control and straw mulch. However, the lowest dry matter content was found in beets planted under compost mulch. The total net return was higher in all mulched plots with compost mulch giving the maximum net return. There were no significant differences observed between the effects of mulches on the three beetroot varieties. However, Detroit dark red and Globe dark red produced the maximum plant height and yield respectively. Based on the results of this study, it can be concluded that mulching was the most effective treatment compared to non-mulched treatment. Therefore, it is recommended for commercial beetroot cultivation in farmers' fields.

Keywords: Beetroot, mulch, organic, variety, plant height, yield, quality, Malawi

Declaration

I, Elizabeth Addo declare that the work in this thesis titled Growth, yield and quality response of beetroot varieties to organic mulches in tropical conditions has been carried out by me under the supervision of Professor Nick Roskruge. The information derived from the literature has been adequately cited. I also declare that no part of this thesis has been previously presented for another degree at this or any institution.

Dedication

I thank the almighty God for granting me the opportunity, faith and strength to successfully complete my studies in New Zealand. I would like to dedicate this thesis to my son Emmanuel Likubwe Phiri who endured my absence during the time I was doing my studies.

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I wish to express my profound gratitude to the following for their support. Firstly, the government of New Zealand and the Ministry of Foreign Affairs and Trade (MFAT) for the much-needed financial support throughout my studies. My profound gratitude also goes to my research supervisor Professor Nick Roskruge (Professor in Horticulture in the School of Environment and Agriculture, Massey University, New Zealand) for his valuable advice and supervision. His enthusiasm and constructive comments made the study a real learning experience. My further appreciation goes to my co-supervisor; Mr Simon Semese (Research Officer in the School of Environment and Agriculture, Massey University, New Zealand) for his guidance and words of encouragement during the entire period of my research.

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CHAPTER 1

Introduction

Beetroot (*Beta vulgaris* L.), also commonly known as red beet, garden beet or table beet, is a popular vegetable crop grown in many parts of the world (Rana, 2018; Stintzing & Carle, 2004). It belongs to the Chenopodiaceae family of vegetables and it is a close relative of Swiss chard (syn. silver beet), sugar beet and fodder beet (Prohens & Nuez, 2008). Red beets are usually grown for their fleshy roots and green tops. They are consumed fresh, cooked or as a processed product (Rana, 2018). Red beets are popularly grown in Europe, Asia and the Mediterranean region and in the United States of America (Montes-Lora, Rodríguez-Pulido, Cejudo-Bastante, & Heredia, 2018).

Beetroot has considerable commercial opportunities worldwide. Several processed beetroot products, such as beet juice and drinks, pickles and beet powder have been made. These are available in both local and international markets (Wruss et al., 2015). Apart from beetroot drinks and pickles, beets have been highly utilized in the food industry. Red beets have demonstrated to possess a high potential for natural dye. Due to the rising consumer demand for natural colourants, they are currently being used in several food industries (Agic et al., 2018; Stintzing & Carle, 2004).

The demand for organic foods or by products in food processing, is escalating as people are concerned with their health. Most of the colourants that are produced on the market, especially cheap ones, are synthetically produced. This can pose a health threat as the concentration of synthetic by products increases in the body. Therefore, the use of red beets as source of natural colourants cannot be underestimated. The intense red colour of beetroot (due to the presence of betalains) has attracted the interest of several food processing industries as a potential natural dye. Recently, there has been high resistance to the consumption of food dyed with artificial colourants due to a lot of health concerns from consumers. It is from this background that food processors have opted for beetroot colourants hence creating a huge market for the product (Georgiev et al., 2010).

Beetroot products have also recently received a lot of attention from consumers due to their antioxidant content. This is good for people with cardiovascular diseases as it helps in fighting against toxic-reactive oxygen species such as hydrogen peroxide (Babagil, Tasgin, Nadaroglu, & Kaymak, 2018).

Most commercial beetroot products contain inorganic nitrate (NO_3^-) as an active ingredient which is reduced to nitric oxide by bacteria (Murray, Paul, Seifert, Eddy, & Halaby, 1989). Clinical trials have shown that high NO levels have a positive effect on the efficiency of muscles and help in fatigue management (Hernández et al., 2012). Additionally, nitrate consumption has been highly associated with reduction of hypertension. This suggests that beetroot products can potentially help in the management of several cardiovascular diseases (Kapil et al., 2010; Lundberg, Carlström, Larsen, & Weitzberg, 2011). However, some studies have shown that high levels of NO are associated with depressive states which need to be taken into consideration when consuming beetroot products (Suzuki, Yagi, Nakaki, Kanba, & Asai, 2001).

Furthermore, beetroot have a comparative advantage as they are easy to produce. They do not require intense and laborious management practices from inception through harvesting and post-harvest. They store well and are not limited by weather patterns (Agic et al., 2018). They also take a very short period to grow, yet they are a high value crop. Studies reveal that they also benefit the environment as they are not hazardous since they do not require heavy chemicals to produce (Agic et al., 2018).

Sugar levels are one of the factors that influence consumer's choice of food. Studies have revealed that beetroot has half the sugar content of sugar beets, also the sugar type is sucrose not fructose. This is an advantage over other fruits and vegetables where the main sugar is fructose. As a result, beetroot juice is ideal for making athletic drinks. (Bavec, Turinek, Grobelnik-Mlakar, Slatnar, & Bavec, 2010).

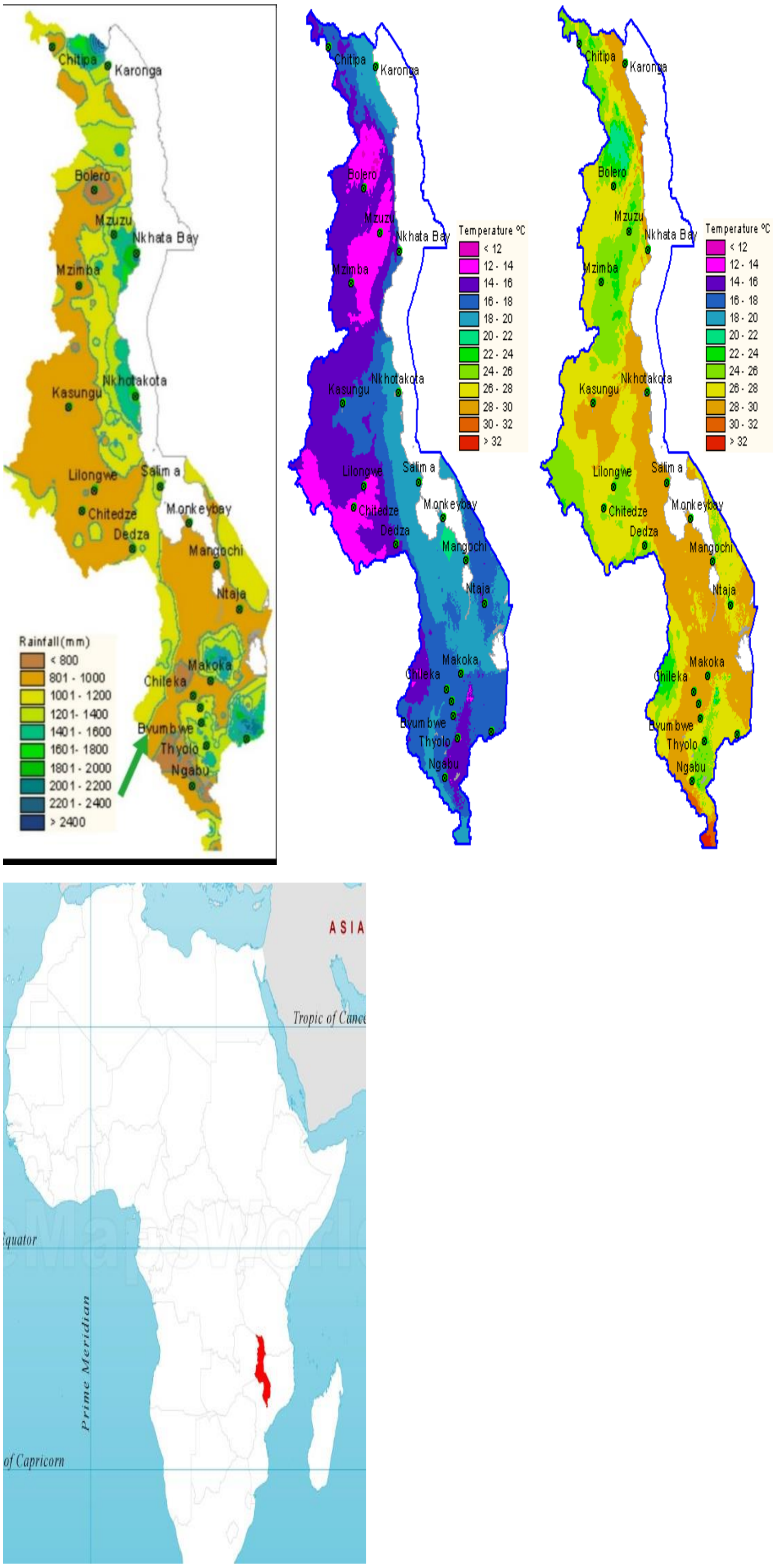

Figure 1: Maps of Malawi showing average annual rainfall, minimum temperature and maximum temperature across the country and Map of Africa (below) showing Malawi (red).

Source: www.metmalawi.gov.mw, accessed on 4 January 2021

Malawi is a landlocked country in the southern part of the Africa stretching across longitudes 32ºE and 36ºE and latitudes 9ºS and 18ºS. The topography is highly varied. Malawi lies within the Great Rift Valley which runs north to south through the country, containing Lake Malawi. The land covers an area of about 9.4 million ha, while 2.4 million ha is covered by water. A total of 5.7 million ha is allocated to agriculture (Chadha, Oluoch, Saka, Mtukuso, & Daudi, 2008). Malawi has a population of over 18 million and depends on agriculture for its economy, which counts for about 42% GDP (Vincent & Mkwambisi, 2017). Furthermore, over 90% of foreign exchange earnings is generated from the agricultural sector (Chadha et al., 2008).

Malawi has a sub-Saharan climate, characterized by one major rainfall season. The weather varies from hot and dry to moist and cool depending on the time of the year (Chadha et al., 2008). Generally, the country has a mild tropical climate similar to other countries in the southern part of Africa (Jury & Mwafulirwa, 2002). The climate is highly influenced by the inter-tropical convergence zone (ITCZ), the subtropical high-pressure belt in the south and topography (Vincent et al., 2014).

Winters are generally cool and dry occurring from May to August, with mean daytime temperature ranges of 17ºC to 27ºC, while night temperatures drop to as low as 5ºC (Vincent et al., 2014). The hot and dry season lasts from September to October with mean temperatures varying between 25ºC to 37ºC (Fig. 1.1). The rainy season which lasts from November to March is mainly influenced by the ITCZ and varies in its timing and intensity from year to year. During the rainy season the ITCZ which marks the convergence of the north-easterly monsoon and south-easterly trade winds, oscillates over the country and frequently connects with troughs in the Mozambique channel (Jury & Mwafulirwa, 2002).

The northwest monsoon is another main rain-bearing system in Malawi and it constitutes a recurred Tropical Atlantic Air which approaches the country through the Congo basin (Chadha et al., 2008). It is believed this system is responsible for well-distributed rainfall over the nation. Floods and cyclones are seldomly experienced when the country is hit by the easterly winds emanating from the Indian ocean (Jury & Mwafulirwa, 2002).

1.1 Problem statement

Production of beetroot is minimal in Malawi, as it is not a well-known crop. Climate change also has a direct bearing on crop management choices, especially where the water table and other water sources are limiting. A lack of awareness of the benefits of the crop is one of the reasons why it is not widely grown. Furthermore, there has been little or no intentional direction by government or institutions to embark on beetroot research. As a result, scientific ways of production and maximising yield have not been documented. Red beets are very important for human health and food processing industries as they are a very reliable source of natural antioxidants and colourants. As a result, they are a good basis for healthy food choices. Heart diseases, such as hypertension, pose a great threat to life as they suddenly occur at a vulnerable age and have no exact cure. Natural remedies such as the use of beets can help in simplifying the potential health risk through stabilising hypertension. It is from this background that this research aims at identifying the best production practice for potential yield of beetroot under varying organic mulches.

1.2 Research justification

The demand for healthy living and lifestyle is at peak, even in African countries, Malawi included. Natural remedies as a source of antioxidants has become a healthy lifestyle choice rather than a religious idea. This is because of increased awareness among consumers and manufacturers at large of the benefits of eating specific food crops even in raw form. As a result, there is potential for the beetroot market to grow in Malawi as the demand is being created and population increases. Local herbal concoctions have been established and people have been paying for such services. It is believed that maximising beetroot yield will help meet the growing demand.

Higher yields affect quality and quantity combined with economic benefits to the grower. Mulching has been associated with increasing vegetable yield as reported by several studies. It has also been reported to improve the soil naturally when organic mulches are used. Since most studies have been done under controlled environments, conducting local research for this crop would be ideal to determine the best mulching practices for increasing yield.

Climate change affects all production systems and beetroot production included. Mulching has been shown to conserve moisture hence maximising water retention and usage. This paper will help the beetroot farmers to utilise both factors for maximum returns even in climatic shock zones.

Malawi lies in the tropical region, which is characterized by highly variable seasonal rainfall between November and April (Gondwe, 2003). Vegetable production is mainly practiced in winter (May- July). However, winters in Malawi are generally cool and dry which makes it difficult to produce good quality high yield vegetables due to poor water supply (Chadha et al., 2008). To ensure optimum yields, optimum soil moisture must be maintained throughout the growing season and one recognised horticultural practice supporting soil water conservation is the use of mulches (Saleha, Md, & Tamanna, 2019).

Mulching has been associated with improvement of soil properties which encourage good crop growth. They contribute to improved soil structure, supply plant nutrients, and reduce the negative impacts of wind and water erosion thus improving growth and subsequently increasing yield and quality in crops. Increase in yield and quality of mulched crops has also been attributed to regulated soil temperature. Mulches also play an important role in weed, pest and disease management. They block light penetration to the soil hence reducing the germination and growth of unwanted plants (Hembry & Davies, 1993). Several studies have reported significant weed suppression in mulched plots (Iqbal, Amjad, Asi, Ali, & Ahmad, 2009).

Buckwheat and rye straw mulches were found to be more efficient in weed suppression compared to non-mulched control (Kosterna, 2014). Further studies have also shown that mulches which are loose such as straw are not efficient in weed management. However, some studies have reported beneficial effects of straw mulch in weed management. Straw mulch produced best results in vegetable cultivation, with grass mulch having the least impact on weed suppression (Sinkevičienė, Jodaugienė, Pupalienė, & Urbonienė, 2009). Mulching can reduce the movement of some insect pests. However, in some cases, mulching can increase the risk of insect pest invasion (Haapala, Palonen, Korpela, & Ahokas, 2014). Mulches modify the cropping environment hence creating a mostly conducive environment for natural enemies which help in insect pest elimination (Hummel, Walgenbach, Hoyt, & Kennedy, 2002).

Farmers will greatly benefit from this study because most agriculture work in Malawi is done by smallholder farmers who contribute over 80% of the total horticultural production (Chadha et al., 2008). The research will also act as a tool for raising awareness and disseminating the significance of beetroot in Malawi and the potential attached to it. As a result, researchers, education institutions and extension officers will also be enlightened about the importance and profitability of mulches in vegetable production. Additionally, the research can potentially influence policymakers to come up with new policies on conservation agriculture as this is the most sustainable practice in the improvement of soil degradation, which is prevalent in Malawi (Ngwira, Aune, & Mkwinda, 2012).

Currently, there is very little information available on the use of mulches in vegetable production in Malawi. Additionally, the little available information is from studies which were conducted under controlled environments, which makes it difficult for farmers to adopt, as there is no proof that this would be feasible and sustainable for local farmers (Stevenson, Serraj, & Cassman, 2014). Therefore, there is a need to close the knowledge gap by conducting a study in local growing conditions which will directly address the current farmers' problem. It is from this background that this study has evolved and focusses on evaluating the impact of two inorganic mulches (straw and compost) on growth and yield of beetroot cultivars grown in Malawi.

1.2.1 Main objective

To determine the response of different beetroot varieties to organic mulches.

1.2.1.1 Specific objectives

1. To assess the response of beetroot cultivars grown under mulch in Malawi (from seed to harvest).
2. To evaluate the effect of mulching on growth, yield and quality parameters of beetroot varieties grown in Malawi.
3. To determine the quality-response of beetroot cultivars to the application of organic mulches in Malawi.

1.2.2 Research questions

1. Will the use of organic mulches improve beetroot production (quality and yield) for Malawian farmers?
2. Will different beetroot varieties respond differently to the application of organic mulch?

1.2.3 Aims of study

1. To compare the effects of two types of organic mulches (straw and compost) on yield and quality of three beetroot cultivars.
2. To evaluate the response of the beetroot varieties to application of organic mulches.

CHAPTER 2

Literature review

2.1 Introduction

This chapter seeks to expound on past and current research carried out by scientists globally and locally. It discusses the origins and botany of beetroot. It also includes the present state of the usage and significance of beetroot globally. Factors affecting production have also been highlighted, citing nutrient, water and climatic requirements etc. It has also considered several aspects of mulching on crop production and marketing. Challenges associated with the use of mulching have also been noted.

2.2 Origin, distribution, and taxonomy of beetroot

Beetroot (Beta vulgaris L.) which is also commonly known as red beet, garden beet or table beet is one of the most popular vegetable crops grown in many parts of the world (Rana, 2018; Stintzing & Carle, 2004). It belongs to the Chenopodiaceae family of vegetables and is a close relative of Swiss chard, sugar beet and fodder beet (Prohens & Nuez, 2008).

Beetroot originates from Asia (*ibid.*) and was originally mainly grown for its greens. More recently swollen root types were developed. Though beetroot is portrayed as a red rooted vegetable, there are several root and leaf colours which exist, hence it has been considered as a colourful vegetable (Goldman, Navazio, Prohens, & Nuez, 2008). Red beets are usually grown for their fleshy roots and green tops and it is consumed fresh, cooked or as a processed product (Rana, 2018).

2.3 Beetroot morphology

2.3.1 The roots

Beetroot produces thick and fleshy roots which are an excellent food reserve (Rana, 2018). Morphologically, the hypocotyl gives rise to the upper portion of the root while the taproot results in the lower portion. Depending on the variety, the external colour of beetroot fruit varies from orange red to dark purple red. However, the interior colour is influenced by several factors, which include cultivar type, temperature, season, soil and nutrition (Rana, 2018). The root colour in beets is due to the presence of Betacyanin and

Betaxanthin which are responsible for the colour in red-violet and yellow beets respectively (Rana, 2018). These pigments, however, are highly influenced by temperature, pigmentation levels are reduced when the temperature is high. Environmental conditions also have a negative bearing on the presence or absence of the pigments in varying beet types. For instance, beets with intense red colour show little or no Betaxanthin levels, yellow beets have no Betacyanin while neither Betaxanthin nor Betacyanin is present in white beets (Rubatzky & Yamaguchi, 1997).

Depending on cultivar, storage roots of beets have different sizes and shapes. On average, root sizes range from 2 to 15 cm in diameter and shapes are either globular or cylindrical and flattened (Rubatzky & Yamaguchi, 1997). Once the shoot emerges, the taproot grows fast and deep into the soil with some cultivars going up to 2 metres. The secondary roots are mostly distributed within 50-60 cm of the surface and the root system provides fair drought tolerance (Rubatzky & Yamaguchi, 1997).

Figure 2: Showing different beet colours; yellow, red and white beets (By Beet man).

2.3.2 The leaves

Beetroot leaves are mostly ovate and cordate in shape and the colour varies from light green to dark red depending on the cultivar (Rubatzky & Yamaguchi, 1997). Leaf rosettes develop in a spiral pattern with older ones on the outside. Studies have shown that foliage, size, colour and shape are also highly influenced by temperature, season, spacing and soil moisture (Rana, 2018). The leaves are edible and used in salads and cooking in different cultures.

2.3.3 Flowers

Flowers are sessile and arise in clusters of 3 to 4 in the axils of bracts and in secondary branches of the inflorescence. The inflorescence, however, develops in the second year and is a large spike. It should be noted that the flowers are very inconspicuous and are borne without corolla but have a green calyx which thickens towards the base as the fruit ripens. They have five stamens and three stigmas (Rana, 2018).

2.3.4 Fruits

Fruits are formed by the cohesion of two or more flowers which are aggregate and are held together by swollen calyx base. Thereafter, they form an irregular dry cork-like body known as a seed or ball. A seed ball forms by aggregation of several flowers which in turn lead to the formation of a multigerm fruit. It is this multigerm fruit that subsequently derives a true seed. The seeds are small, kidney-shaped and they are reddish-brown in colour. The seed ball contains more than one seed and has a life span of about 5-6 years under normal storage conditions (Rana, 2018).

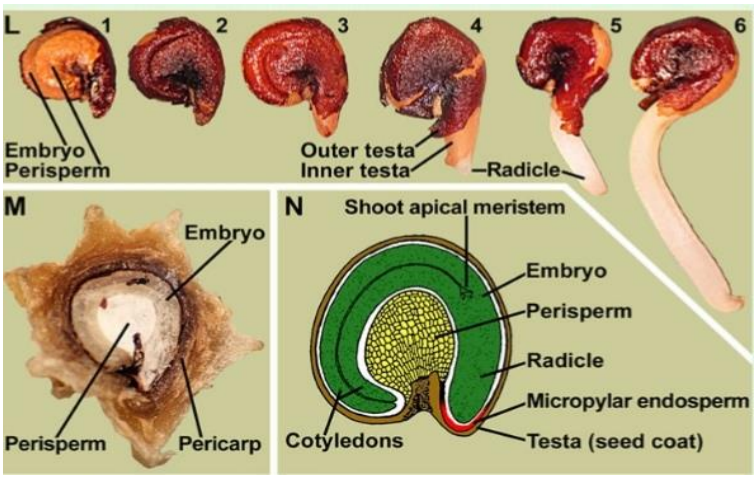

Figure 3: Stages of beet seed germination (L), (M) mature fruit showing perisperm, pericarp and embryo and (N) a modified seed beased on peripheral location of embryo

(Source: Hermann et al. 2007).

2.4 Propagation

The main propagation method for cultivated beets is by seeds. Beet seeds are multigerm, a property which is responsible for the production of roots of various sizes, shapes and harvest maturity. Currently, there are a few monogerm beet seeds which have been developed with more emphasis on sugar beet rather than table beet (Irving, Boulton, & Wade, 2000). Multigerm seeds may contain several true seeds in one ball and in some cases all the seeds may germinate which results in unevenly spaced plants. This should be taken into consideration when planting. Additionally, seed germination occurs over a prolonged period which results in non-uniform germination, resulting in non-uniform maturity and root size (Taylor et al., 2003).

Some studies have shown that beetroot seeds have a low germination rate which is attributed to the presence of the ovary cap, the mucilaginous layer which surrounds the seed ball and the presence of seed inhibitors in the seed ball (Nottingham, 2004). To obtain a more uniform stand with multigerm seeds, various seed treatment mechanisms have been devised and have proven to significantly reduce non-uniform germination. Decortication which is the removal of the rocky surface has been used to produce uniform seeds through reducing the seed ball to the size of a single seed and reducing the mucilaginous layer and some inhibitors (Irving et al., 2000). Other methods which include pre-soaking seeds in hydrogen peroxide, water or salt solution have been found to promote uniform germination in beets (Nirmala & Umarani, 2008).

Germination is highly affected by temperature. Good germination results have been obtained when temperature ranges from 8ºC to 30ºC with best results being obtained from temperature ranges of 18ºC to 30ºC (Rubatzky & Yamaguchi, 1997). For a successful beet crop, seeds are planted at a depth of 1.5-2.5 cm and plant spacing depends on the use of the crop. For a fresh market, plants should be spaced between 4-5 cm and 40-60 cm for the rows. Beets which are meant for processing should be planted closer as whole processed beets have a greater value (Rubatzky & Yamaguchi, 1997).

2.5 Seed production requirements

Beetroot is a biennial crop grown as an annual crop for the market (Holder, 2003). But as a biennial, it requires a photo thermal induction to facilitate the process from vegetative to reproduction phase. Vernalisation is the first element in the induction, this requires low temperature during the rosette stage for the induction of flowering (Abo-Elwafa, Abdel-Rahim, Abou-Salama, & Teama, 2006; Salimi & Boelt, 2019).

Stem elongation, which is also known as bolting, is initiated by the completion of vernalisation and the bolter is the main stem in beets. Different cultivars have different bolting tendencies even within cultivars of the same variety. Studies have shown that when beets are exposed to temperatures lower than the optimum during flowering and seed ripening, seeds do not fully vernalize (Salimi & Boelt, 2019). Beets require long days to induce flowering and the process occurs over 3-4 weeks. The seeds in beets develop inside the irregular fruit and consist of a pericarp and an operculum which forms the ovary cap and covers the true seed. The seed comprises of 2-5 embryos which are supported by a diploid perisperm (Jagosz, 2018). The seeds which consist of more than one embryo are said to be multigerm while monogerms are seeds comprised of one embryo (Salimi & Boelt, 2019).

Figure 4: Monogerm (A) and multigerm (B) seeds

(Source: Zahra and Boelt, 2019)

2.6 Nutritional importance of beetroot

Beetroots are highly nutritive as they are packed with several vitamins, proteins, carbohydrates, minerals and antioxidants which have some ant carcinogenic, antibacterial and antiviral properties (Kanner, Harel, & Granit, 2001). Beetroot leaves are a good source of Vitamins A, B1 and B2 (Rana, 2017). Additionally, beetroot leaves are packed with several antioxidants such as betalains, flavonoids and polyphenols which are capable of counteracting dangerous reactive species (ROS) (Lee et al., 2009).

2.7 Climatic requirements

2.7.2 Temperature

Beets can be successfully grown in hot tropical to cold temperate areas. However, most beetroot varieties perform well in cool temperature conditions and grow well in temperature ranges of 15ºC to 19ºC while germination occurs at temperatures ranges of 4.5 to 24.5ºC. Studies on sugar beet showed that root development is facilitated by a temperature range of 18ºC-25ºC. However, temperatures below 10ºC and above 30ºC facilitate reproductive growth rather than vegetative growth while any temperature above 25ºC during root formation results into smaller root sizes (Kenter, Hoffmann, & Märländer, 2006).

Quality beetroot is best produced when temperature ranges from 10ºC-18ºC (Kumar, 2015a). Previous studies have shown that temperature ranges of 0ºC-15ºC for a minimum period of 5 weeks play an important role in vernalisation (Abo-Elwafa et al., 2006; Mutasa-Göttgens et al., 2010). Severe hot weather conditions can badly injure young plants. Though older beet plants can tolerate heat, prolonged hot weather conditions may retard growth and cause coarseness, undesirable flavour and result in roots which have white concentric rings (Rana, 2017).

Beetroot thrives in cool climatic conditions, though it can also be successfully grown under warm climatic conditions. Studies have shown that optimum temperature ranges of 18ºC-21ºC are best for beetroot production as they facilitate fast growth and beetroot development (Rubatzky & Yamaguchi, 1997). Any temperature lower than 10ºC causes bolting before the root attains its marketable size. Furthermore, sugar accumulation in beets is greatly affected by temperature. Any temperature above 30ºC results in reduced sugar accumulation (Rana, 2017). Additionally, beets which have been grown under high-temperature conditions have less red colour and distinct zoning inside the flesh. For proper root development, abundant sunshine is ideal. Studies have shown that a minimum of 12 hours of sunshine daily is ideal for proper root formation. Additionally, for good quality roots, continuous cool weather conditions for two weeks is good for the development of good colour and texture as fluctuating temperatures cause zoning. Under proper growth and management conditions, beetroot yield can go as high as 50t/ha with an average of 25 to 30 t/ha in most varieties (Rana, 2017).

2.7.3 Rainfall requirements

For optimum yield, beetroot requires an average of 300 mm of rainfall in a growing season (Rana, 2017). However, due to poor rainfall patterns in most tropical areas, the amount of water required to produce optimum growth, yield and quality is often not achieved during the growing season which is normally cool and dry (Saleha et al., 2019). To optimise beetroot yield in such growing conditions, proper water management practices are crucial for maximizing profit. Mulching which involves covering the soil with any material, natural or synthetic, can modify some soil properties, including soil moisture and retention, soil temperature and some chemical soil properties, hence increasing soil productivity and improving crop growth, yield and quality (Saleha et al., 2019).

2.8 Soil types

Soil conditions highly influence beetroot yield and quality. A wide range of soil types have been proven to favour beetroot cultivation. However, soils which are deep and well-drained loam or sandy loam soils are best for beetroot production (Rana, 2017). Heavy soils can satisfactorily produce beets. However, beets grown in heavy soils tend to have undesirable shape. Soil pH plays a vital role in beetroot production. Studies have shown that beets grow best in soils with an optimum pH of between 6-7 (Rubatzky & Yamaguchi, 1997). However, red beets can tolerate alkaline soils with a pH as high as 9-10, though very high pH levels have been found to promote scab, a soil borne disease. On the other hand, any pH below 5.8 has been associated with yield losses (Rana, 2017).

2.9 Nutrient requirements

To maximize yield in beets, proper management of factors which influence growth and yield in beetroots such as water and nutrition are essential (Barlog, Grzebisz, Peplinski, & Szczepaniak, 2013). Beetroot belongs to a group of vegetables considered to be heavy feeders and requires an optimum amount of major plant nutrients (N, Na, P, K) to maximize yield (Dos Santos et al., 2017).

Nitrogen plays a vital role in facilitating growth and yield in plants. It forms a major component of proteins, enzymes, vitamins and is responsible for chlorophyll and amino acid formation in plant cells (Petek et al., 2012). Nitrogen availability and timing is crucial as it has a substantial but variable uptake by the crop (Nottingham, 2004). Though nitrogen can significantly increase yield, excess can potentially harm the environment and increase vegetative growth at the expense of root formation (Feller & Fink, 2004). In potatoes, studies have shown that higher than the optimum application of nitrogen can lead to delayed maturity and competition between tubers and leaves and result in lower yields (Najm, Hadi, Darzi, & Fazeli, 2013).

Beetroot is sensitive to any lack of nutrients. Studies have shown that NPK fertilizers applied at 150 to 200 KgN/ha, 70 to 100 KgP/ha and 30 to 50 KgK/ha give optimum yield of beets with high betamine content and low vulgaxanthine and nitrate contents (Felczyński & Elkner, 2008). A study conducted in Ethiopia showed that urea (46% N) application on beetroot had a significant effect on leaf area and dry weight (Tamiru et al., 2017). Potassium is equally important in beetroot production. A yield of 33 t/ha was attained when 93.2kg/ha of potassium was applied (Abera, 2019). Apart from major plant nutrients, beets require optimum levels of boron, zinc and sodium and sometimes these are applied to meet the needs for minor plant nutrients (Rubatzky & Yamaguchi, 1997). All nutrient additions are subject to soil tests prior to planting which identify the soil limitations or nutrient values.

2.10 Water requirements

Correct water supply is essential to maximize yield by providing a uniform growth rate. Moisture is required to facilitate uniform germination but should not be applied in excess at this stage as it can restrict gas exchange resulting in poor germination. After seed emergence, dry conditions can negatively affect growth and yield (Hoffmann, 2010). To obtain a good crop, excessive watering should be avoided as waterlogged conditions will result in poor root development, leach nutrients and promote diseases. Keeping soil moisture at optimum levels will improve growth, yield and quality in root vegetables such as beetroot (Nottingham, 2004)

2.11 Varieties

Apart from environmental conditions, variety is another factor which determines yield and root size for beetroot. Some varieties also have inherent disease or pest resistance. Disease resistance is key for a successful harvest where high disease pressure exists (Nottingham, 2004).

For the processing industry, regular, globe-shaped, uniform dark red cultivars are preferred over others (Barański, Grzebelus, & Frese, 2001). Additionally, processing markets require high soluble solid contents, hence cultivars with high sugar content are preferred. This reduces the need to add sugar hence reducing costs (Irving et al., 2000).

Colour is another factor which is a varietal property and the market or use determines which colours are preferred. Dark red varieties are the most preferred for the processing industry. However, some external factors such as environment can also influence the colour of the root (Gaertner & Goldman, 2005). Studies have shown that lower temperatures are good for darker pigmentation and total soluble solids content (Irving et al., 2000).

Another variety of importance is the cylindrical beets. These beets can produce roots of suitable diameter and are high yielding. Yield potential is an important factor to consider in beetroot cultivation. Apart from variety, other factors such as spacing have an impact on the yield of beets. Studies have shown that higher yields have been achieved when plant densities are low (Goldman, 1995).

Figure 5: Showing different beetroot varieties. Globular, cylindrical and intermediate (from left to right) (By Beet man)

2.12 Effect of mulching on soil moisture content

The role of organic mulches on soil moisture is well documented. Sinkevičienė et al. (2009) reported significantly higher soil moisture content in plots which were mulched compared to control plots. Furthermore, it was also noted that soil moisture was stable in mulched plots throughout the growing cycle, compared to plots without mulch which recorded fluctuating soil moisture content. Similar results were found when turmeric plants were grown under organic mulches. A study investigating the effect of organic mulches on growth, yield and moisture content in rain fed grown turmeric showed that mulched plots had higher soil moisture content which influenced total marketable yield (Kumar, Pandey, & Nath, 2008).

Mulching increases rain or irrigation water infiltration through the reduction of runoff. A significantly higher moisture content was reported on soils under sesame straw, sorghum straw, rice straw and Sudan straw compared to no mulch, mulches improved soil moisture content at 0-0.2, 0.21-0.4 and 0.41-0.6 depths (Teame, Tsegay, & Abrha, 2017). However, sesame mulch was more effective at soil water conservation compared to the other organic mulches. These findings are in accordance with results from other studies on the effect of mulching on soil moisture content (McMillen, 2013; Shirgure, 2012).

A mulching trial that was conducted with inorganic and organic mulches in lime acid soils showed that both mulch types improved soil moisture compared to the uncovered soil. However, towards the end of the crop cycle, the soil under inorganic mulch had significantly higher moisture content compared to the soil under organic mulch. This was attributed to the decomposition of the organic mulch which might have reduced surface area (Shirgure, 2012).

Mulches protect the soil from direct exposure to the sun, reducing evaporation of water from the soil surface. Mulch also prevents runoff through facilitating the absorption of the impact of the raindrops and allowing higher infiltration rates (Shirgure, 2012). An experiment that was conducted to evaluate the effect of different thicknesses of wheat straw, grass clippings and leaf debris on moisture conservation found that mulch type had no significant impact on soil moisture content. However, mulched plots had significantly higher moisture content compared to plots without mulch. On the other hand, mulch thickness was found to have a significant effect on soil moisture. The thicker the mulch the higher the soil moisture content (McMillen, 2013).

Sarkar et al. (2019) stated that maximum soil moisture retention was found in plots which had coloured plastic mulches in an experiment that was conducted to assess the response of onions to polyethylene mulches. The results were attributed to lower evaporation rates in mulched plots. However, black and blue plastic mulches had the least soil moisture retention compared to the other lighter coloured mulches.

Different organic mulches increased soil moisture in an experiment that was conducted under a controlled environment in two different seasons. Results showed that mulching increased soil moisture content in both the dry and wet seasons. (Sadek, Youssef, Solieman, & Alyafei, 2019). Adekiya, Agbede, Aboyeji, and Dunsin (2017) conducted an experiment with the aim of evaluating the impact of mulches on moisture in dry land grown shallots. Results showed that mulching improved moisture content with organic mulches outperforming plastic mulches (Lasmini, Wahyudi, Rosmini, Nasir, & Edy, 2019).

A South African study showed that mulching with different organic mulches improved soil moisture content at 10 cm depth in an experiment evaluating the impact of mulching on soil moisture, nitrogen and weed growth on irrigated maize. However, no differences were observed at 30cm depth among the treatments (Murungu, Chiduza, Muchaonyerwa, & Mnkeni, 2011). Awodoyin, Ogbeide, and Oluwole (2010) reported improved soil moisture content in all mulched plots in an experiment using both organic and inorganic mulches. However, plastic mulch outperformed organic mulch. Likewise, mulches of different materials increased soil moisture content with time, with higher moisture being obtained from plastic mulch treatment than the plot which had organic mulch (Bhutia, Singh, & Reddy, 2017).

Kumar (2014) stated that mulching significantly improved soil moisture at 15 cm and 30 cm depth in an experiment on Eureka lemons. An experiment that was conducted to assess the impact of mulching on grain yield of upland rice found that all mulched plots had significantly higher moisture content in comparison to control plots. Mulching improved soil moisture by about 17% (*cf* control) in an experiment conducted in different environments to assess the impact of mulches on chilli plants (Godawatte & De Silva, 2014).

2.13 Effect of mulching on soil temperature

Mulching is associated with promoting warm soil temperatures as heat is trapped by the mulch and heats the soil beneath it. Polyethylene and straw mulches increased soil temperature in groundnut plots with polyethylene mulch outperforming straw mulch (Ramakrishna, Tam, Wani, & Long, 2006). However during hotter months, mulches, especially from organic sources, decrease soil temperature which promotes good crop growth. An experiment was conducted to assess the impact of organic mulches, viz straw, peat, sawdust and grass on soil properties, and results showed that organic mulches significantly lowered soil temperature in relation to the control (Sinkevičienė et al., 2009). Similarly, Agrawal, Panigrahi, Sharma, and Agrawal (2010) stated that the application of weed mulch in rain-fed maize reduced soil temperature by about 4ºC and 3ºC at 5 cm and 15 cm soil depths respectively.

In an experiment conducted to evaluate the effect of mulching on tomato yield, Singh and Kamal (2012) reported a more than 2ºC improvement in soil temperature in plots which were mulched with black polyethylene. However, the effect of black polyethylene was more significant during the early stages of crop growth when the tomato plants provided less shade to the soil surface. The higher temperature in black polyethylene mulch was attributed to greater net radiation compared to other treatments. Similarly, black polyethylene improved soil moisture in crops such as lettuce, okra and squash (Mahadeen, 2014). Additionally, plastic mulches significantly increased maximum, minimum and mean soil temperatures compared to the control in a Scandinavian winter wheat crop (Ibarra-Jiménez, Zermeño-González, Munguia-Lopez, Rosario Quezada-Martín, & De La Rosa-Ibarra, 2008).

Straw and compost mulches improved soil temperature, with compost mulch outperforming wheat straw mulch (Cook, Valdes, & Lee, 2006). Similarly, in a separate trial, polyethylene and straw mulch produced the highest soil temperatures with no significant differences among them. However, it was observed that at 10 cm soil depth there was little temperature difference (Ramakrishna et al., 2006). Sarkar et al. (2019) reported that mulching with coloured plastic mulches, viz. olive polythene film, silver polythene film, white polythene film, black polythene film and blue polythene film, improved soil temperature in an experiment on onion crops. In this trial, black and blue plastic mulches outperformed other mulch colours. The results were attributed to the efficiency of black materials in heat absorption from solar radiation as compared to white-coloured materials which are poor heat absorbers. Comparably, coloured plastic mulches increased soil temperature by 1-7ºC in comparison to the control. However, darker colours namely; blue and black outperformed other colours (Gordon, Foshee, Reed, Brown, & Vinson, 2010).

Mulching improved soil temperature towards the end of the cropping period in an experiment that was conducted to evaluate the impact of organic mulch, degradable and non-degradable plastic mulches on growth and yield of winter rapeseed. The increase in soil temperature was achieved by suppression of latent heat. However, the increase in temperature was more obvious in plots which had transparent plastic mulch (Subrahmaniyan & Zhou, 2008). In an experiment evaluating the impact of organic mulches on soil properties, growth and yield of cantaloupe, mulches reduced both maximum and minimum soil temperature in comparison to control (Sadek et al., 2019). Similarly, mulching with different materials significantly reduced soil temperature in plots of okra in an experiment that was conducted in different seasons (Adekiya et al., 2017).

Different plastic mulches increased soil temperature in an experiment assessing the effect of mulching on growth, yield and profitability of pepper (Thwe, 2020). Organic mulches significantly reduced mean soil temperature at 5 cm depth in an experiment that was conducted in a warm environment to evaluate the impact of mulching on irrigated maize. However, no significant differences were observed at 10 cm depth among the mulch treatments (Murungu et al., 2011). Organic mulches reduced soil temperature throughout the growing period of chilli plants in an experiment conducted under stress conditions. Mulching with plastics increased soil temperature by 2 to 4ºC in comparison to reflective mulch and the control (Andersen, Olson, Momol, & Freeman, 2012). Awodoyin et al. (2010) stated that mulching increased temperature in comparison to the un-mulched control in an experiment evaluating the impact of mulching on soil properties, weed control, yield and growth in tomato plants.

Different plastic and biodegradable plastics influenced soil temperature in an experiment evaluating the feasibility of substituting plastic mulches with degradable mulches in broccoli (Lopez-Marin, Gonzalez, Fernandez, Pablos, & Abrusci, 2010). Mulching with coloured plastic mulches improved soil temperature by 1.2ºC and produced the highest soil temperature in a controlled environment trial in Pakistan (Iqbal et al., 2009). Different mulch colours had a different impact on the root zone temperature in a study assessing the effect of coloured plastic mulches on growth and productivity of broccoli. The results showed that all six coloured plastic mulches increased the root zone temperature in comparison to the control in both winter and spring. However, the black plastic mulch produced the highest root zone temperature in both seasons (Khater, Hamouda, & Mostafa, 2020). A study evaluating the effect of polyethylene and two degradable plastic mulches on growth and yield of tomatoes found that all mulches increased the mean soil temperature in comparison to the control (Alamro, Mahadeen, & Mohawesh, 2019).

An experiment evaluating the effect of inorganic and organic manure on the performance of dry land grown shallots showed that mulching reduced the mean soil temperature in comparison to the control, and that organic mulches outperformed inorganic mulches (Lasmini et al., 2019). Lehar, Wardiyati, Moch Dawam, and Suryanto (2017) reported improved temperature regulation in soils with rice straw mulch. The results showed that the temperature in plots with straw mulch were 10ºC cooler than the control. Oxo degradable and black plastic mulches improved soil temperature in an experiment conducted in different locations to assess the effect of the mulches on soil temperature, growth and yield of cucumbers (López-Tolentino et al., 2017).

A two year experiment evaluating the impact of plastic and organic mulches on soil temperature, soil-borne diseases and growth in tomatoes showed that mulching increased temperature in both years, with the control having the lowest soil temperature. However, the transparent plastic mulch produced a higher soil temperature in comparison to organic mulch (Moursy, Mostafa, & Solieman, 2015). In a Scandinavian trial on mulches the mean maximum soil temperature was improved by the application of coloured plastic mulches in comparison to the control. However, no differences were observed in the mean minimum soil temperature among the treatments (Ruíz-Machuca et al., 2015).

Plastic and organic mulches raised minimum soil temperature in a two-year study conducted on cauliflower. However, maximum temperatures were less conclusive as the plastic mulch raised the maximum temperature whilst organic mulches reduced the maximum soil temperature (Kumar, Sharma, Kumar, Singh, & Kumar, 2019). Similarly, plastic mulches increased temperature in winter grown cauliflower plots, resulting in earlier harvest than the control (Job, 2018). The lesser known Nylon inorganic mulches increased soil temperature in an experiment on cucumbers. (Babatunde, Shittu, Adekanmbi, & Asimi, 2020).

2.14 Effect of mulching on Pests and diseases and weeds

The role of mulching in pest and disease control is well documented. Apart from controlling pests and diseases, mulches promote the efficiency of non-chemical and integrated pest control measures (Brown & Tworkoski, 2004). An experiment evaluating the effect of compost mulch on weed, fungal and insect pest control found that compost mulch reduced weeds for almost a year after its application. Furthermore, compost reduced growth of brown rot fungus (*Monilia fructi cola*) on stone fruits compared to sterilized compost substrate. Insect Pests such as arthropods, leaf miner and migrating woolly apple aphid nymphs were all significantly reduced by the application of compost mulch in orchard systems (Brown & Tworkoski, 2004).

Research has shown that the use of UV plastic and straw mulches delayed colonization of insect pests in zucchini squash. Mulching significantly reduced seed-borne pathogens in tomatoes compared to pre-seed chemical treatment and crop without mulch (Sibuga, 2010). Different mulch materials offered considerable control of *Botrytis cinerea* in an organic strawberry production (Daugaard, 2008). Mulches can reduce the use of fungicides in vegetable fields as they help reduce foliar disease incidence.

An experiment assessing the effect of straw mulch on onions found that it significantly reduced onion thrips (Larentzaki, Plate, Nault, & Shelton, 2008). Similarly, UV plastic mulches significantly reduced the abundance of onion thrips population in a New Zealand based trial (Till, James, & Teulon, 2004). Mulching with polyethylene film and straw significantly reduced weed population in groundnut fields in Vietnam (Ramakrishna et al., 2006). Several types of reflective mulches such as silver or grey have been used to delay and reduce the occurrence of virus diseases in several crops (Brown et al., 1993). Reflective mulches reflect short wave light which keeps out incoming aphids, reducing their effect on plants. Brown and Tworkoski (2004) reported a significant reduction of aphids on squash grown with reflective mulch. Studies have shown that organic mulches which contain nitrogen have been used effectively in controlling soil-borne pathogens (Gamliel, Austerweil, & Kritzman, 2000).

The physical barrier created by mulch is important in the prevention of weed seed emergence. Organic mulches reduced weeds as well as weed dry matter in an experiment which worked with maize over two seasons (Murungu et al., 2011). Similarly, mulching reduced weed infestation in outdoor tomato crops which were grown under both plastic and organic mulches. However, plastic mulch was more effective in weed control and resulted in less herbicide usage (Awodoyin et al., 2010).

Indulekha and Thomas (2018) stated that mulching with organic materials reduced weeds in turmeric plots. Similar results were reported by Thankamani, Kandiannan, Hamza, and

Saji (2016) who reported that mulching with paddy straw, coir pit compost and other coloured plastic mulches significantly reduced weed density, as evidenced by low dry weed biomass production in mulched plots. Another study found that mulches made from cranberry fruits and leaves improved weed control in an established blueberry field (Krogmann, Rogers, & Kumudini, 2008).

2.15 Effect of mulching on plant height

Mulching has several benefits on crop growth. It improves soil productivity through prevention of runoff, soil loss and checking water loss from the soil surface. As a result, it regulates soil temperature and improves the physical, chemical and biological properties of soil. These factors enhance plant growth (Ashrafuzzaman, Halim, Ismail, Shahidullah, & Hossain, 2011). A study on tomatoes showed that mulching improved growth on tomato plants as higher plant growth was obtained from plots which were mulched (Awodoyin et al., 2010). However, no differences were observed among the different mulch treatments. This agrees with Ashrafuzzaman et al. (2011) who reported significant growth in chillies planted under mulch. Growth parameters such as plant height, number of branches, number of leaves and stem diameter were higher in mulched treatments compared to control plants. The increase in growth was attributed to mulching. Carmichael, Shongwe, Masarirambi, and Manyatsi (2012) reported improved plant height in mulched radish plants grown under different irrigation regimes.

Wheat straw mulch produced the highest main vine length in cantaloupe plants grown under different organic mulches in a multi-season experiment (Sadek et al., 2019). Similarly, mulching with different materials increased plant height in ginger plants grown in different seasons. Organic mulches produced superior results, followed by polyethylene mulch (Kushwah, Dwivedi, & Jain, 2013). Paul, Mishra, Pradhan, and Panigrahi (2013) stated that mulching improved plant height in capsicum plants by about 55% compared to the non-mulched control. Comparably, mulching improved height in okra plants in two growing seasons and grass mulch outperformed other organic mulches (Adekiya et al., 2017). Mulching significantly increased plant height of capsicum in comparison to the control from 35 to 105 days after sowing. Black plastic mulch was superior over other colours (Thwe, 2020).

Teame et al. (2017) reported a significant increase in plant height in sesame plants grown under organic mulches. The improved plant height was attributed to higher moisture content in mulched plots. Different mulch materials have been utilized to improve growth in several crops. Kumar, Singh, Hooda, Singh, and Singh (2015) reported higher plant height in potatoes, sesame and chillies (Ahmad, Hussain, Raza, Memon, & Naqvi, 2011). Mulching significantly increased plant height in green beans grown under inorganic and organic mulches. However, organic mulch had the highest plant height compared to other mulch treatments (Kwambe, Masarirambi, Wahome, & Oseni, 2015).

Mulching produces crops which are more consistent than crops grown on bare soil. Tomato plants grown under different mulches had their growth improved compared to non-mulched tomatoes (Awodoyin et al., 2010). These results are similar to other findings on tomato plants grown under mulch (Gao et al., 2001). Different mulch materials improved growth parameters such as plant height in all mulched plots in an experiment assessing the effect of mulching on growth and yield in garlic plants (Gessesew & Tsion, 2017). Similarly, mulching improved growth in tomatoes in comparison to control (Moreno & Moreno, 2008). A study assessing the impact of mulches on onions found that mulching improved plant height compared to control plants (Rachel, Mondal, Pramanik, & Awal, 2018). Similarly, biodegradable plastic mulches significantly improved plant height in sweet corn in comparison to control plants (Ghimire, Scheenstra, & Miles, 2020).

Mulches significantly influenced vegetative growth in some tomato varieties in an experiment on different tomato varieties. Some tomato varieties outperformed other varieties, though all mulched tomatoes had higher vegetative growth than those grown on bare soil (Bender, Vabrit, & Raudseping, 2008). Application of organic and inorganic mulch improved height in okra plants in comparison to bare soil (Bhutia et al., 2017). Mulching also increased plant height in chilli plants grown in different environments (Godawatte & De Silva, 2014). Plastic mulches improved height in hot pepper plants, grown under different plastic mulches. Black plastic mulch produced the tallest plants while the un-mulched soil had the lowest plant height (Iqbal et al., 2009).

Yaghi, Arslan, and Naoum (2013) stated that mulches improved water use efficiency in drip-irrigated cucumbers, thereby improving vegetative growth. Similarly, mulching improved seedling emergence and height in okra and squash. The improved vegetative growth in these two summer vegetables was attributed to improved moisture retention in mulched plots (Mahadeen, 2014; Makus, Tiwari, Pearson, Haywood, & Tiarks, 1994).

Mulching increased plant height in onion crops at subsequent days after planting. The increase in plant height levelled off after 50 days from planting, due to drying up of the mulch. Straw mulch produced the tallest plants which were statistically equivalent to black polyethylene mulch (Islam, Ahmed, Hossain, & Chowdhury, 2002).

An experiment evaluating the effect of three mulches on strawberries grown under two different environments showed that the effect of mulch depended on the environment (Pandey, Singh, & Maurya, 2015). Similarly, mulching improved two strawberry varieties as evidenced by higher plant height. However, black polyethylene gave the best results compared to rice straw and water hyacinth (Adnan, Rahim, Tamanna, & Hossain, 2017). Additionally, strawberry plants grown on plots mulched with different organic mulches recorded higher vegetative growth as evidenced by the higher length of runners compared to control plants. The growth increase was attributed to higher levels of nitrogen in mulched plots, due to decomposition and release of nutrients from the organic mulches (Kivijärvi, Parikka, & Tuovinen, 2002).

In another study, different mulch materials significantly improved plant height in strawberries (Sharma & Sharma, 2003). Parmar, Polara, and Viradiya (2013) reported an improved growth in watermelons grown under different mulch materials. All growth parameters which were measured, such as length of the main vine, number of branches and number of nodes per vine were significantly higher in all mulched treatments. Mulching improved plant height in cucumbers by up to 75% (Agrawal et al., 2010). Similar findings were reported from an experiment evaluating the response of tomatoes and eggplants to mulches. Mulch treatments improved plant growth in both vegetables. However, superior results were obtained from the plot using plastic mulch compared to plots mulched with cassava peel, guinea grass and giant star grass (Asiegbu, 1991).

Hallidri (2000) reported that different mulch materials had a similar effect on growth of tomato plants. Plant height was significantly affected by all the mulch materials in comparison to control. Similarly, tomato plant height was significantly improved by different mulches compared to control plants (Kayum, Asaduzzaman, & Haque, 2008). Mulching also had a significant effect on plant height in okra, with superior results obtained from the crop with plastic mulch than the organic mulch (Kumar, Babu, Abishkar, Shailesh, & Bhishma, 2018). Kumar and Dey (2011) stated that mulching facilitated root growth in strawberry plants which subsequently improved nutrient uptake by the plant, hence improving plant height. Comparably, mulching improved length of vines in several vegetables. Watermelons had their vine length significantly improved by different plastic mulches (Andino & Motsenbocker, 2004).

Mulching improved plant height in okra grown in two different seasons in relation to the control (Gordon et al., 2010). Water hyacinth mulch increased plant height in carrots grown on vermicompost and mulch (Hasan et al., 2018). Different organic mulches significantly improved height in turmeric plants in different growing seasons compared to the crop which was grown under bare soil (Indulekha & Thomas, 2018).

Inorganic and organic mulch improved plant height in ginger in relation to the control, with exceptionally higher plants in paddy straw mulch (Thankamani et al., 2016). An experiment conducted over 3 years assessing the effect of mulching on rain fed rice found that plant height was significantly improved by the application of mulch. However, the mulch effect was different each year due to differences in rainfall pattern over the period (Kato, Kamoshita, Abe, & Yamagishi, 2007). Rice straw mulch improved plant growth in comparison to silver or lack plastic mulch in potato plants grown in a medium-altitude area of Indonesia (Lehar et al., 2017). Similarly, mulching increased plant height in sweet pepper in comparison to the control (Arogundade, Salawu, Osijo, & Kareem, 2019). Mulching with straw produced the tallest plants in tomatoes grown under organic and inorganic mulches (Chattha & Hayat, 2005). Black nylon mulch increased plant height in cucumbers in comparison to white plastic (Babatunde et al., 2020). Mulching with organic and inorganic mulches produced higher plants in Eureka lemons (Kumar, 2014).

2.16 Effect of mulching on number of leaves

Karaye and Yakubu (2006) reported a significantly higher leaf number in garlic plants grown under mulch. Similarly, Gessesew and Tsion (2017) stated that mulching improved leaf numbers in all garlic plants grown under mulch. Different indigenous mulches significantly increased the number of leaves in tomato plants (Kayum et al., 2008). Sharma and Sharma (2003) reported of higher number of leaves in strawberry plants grown under mulch. The results were attributed to improved moisture retention and weed suppression in mulched plots. Similarly, strawberry plants grown with three different mulches had a significantly higher number of leaves compared to control plants (Adnan et al., 2017). Furthermore, mulching with organic and inorganic materials produced more leaves in summer squash (Chaurasia & Sachan, 2020). Bharat et al 2020 reported a significantly higher number of leaves in potato plants grown under mulch than the control.

Pandey et al. (2015) reported improved leaf numbers in strawberry plants grown with mulch in different growing conditions. Similarly, mulching significantly increased the number of leaves on onion plants in relation to control plants (Islam et al., 2002). Likewise, mulching improved the number of leaves in various lettuce crop trials (Moniruzzaman, 2006; Saleh, Abu-Rayyan, & Suwwan, 2009). Onions grown with mulch had significantly higher number of leaves than control plants (Abdel, 2006). Green polyethylene mulch increased the number of leaves in strawberry plants compared with other mulch types (Priyamvada, Ram, & Meena, 2012). Different organic mulches increased the number of leaves in table beets, with sawdust outperforming other organic mulches (Acharyya, Banerjee, Mukherjee, Mandal, & Sahoo, 2020).

Different mulch materials highly influenced the total number of leaves per plant in chillies. Polyethylene mulch outperformed rice straw, wheat straw and burgess soil covers (Ahmad et al., 2011). An experiment assessing the impact of natural and synthetic mulches on the growth and yield of garlic found that at all growth stages the number of leaves in all mulched plots were higher than the control (Haque, Islam, Karim, & Khan, 2003). Similarly, mulching had a significant effect on the number of leaves in onions. The results showed that coloured plastic mulches increased the number of leaves in comparison to the non-mulched control (Sarkar et al., 2019). Sadek et al. (2019) stated that different organic mulches increased the number of leaves in cantaloupe plants grown in a controlled environment. The control had the least number of leaves. Additionally, organic mulches influenced the number of leaves in organically grown carrots with the least number of leaves in the non-mulched control (Hasan et al., 2018).

Kushwah et al. (2013) stated that mulching with different materials increased the number of leaves and tillers in a ginger crop grown over two seasons. The control had the lowest number of leaves and tillers. Paul et al. (2013) reported significantly higher number of leaves in capsicum plants grown under drip irrigation and mulching. The results were attributed to improved water use efficiency as mulched plots had the highest moisture retention. Adekiya et al. (2017) reported significantly higher number of leaves in mulched okra plants which were grown in the dry season in comparison to the wet season grown crop. The results were attributed to the improved soil moisture retention which was very apparent in the dry season. However, the number of leaves of the crop grown in the wet season was higher in comparison to the control. Similarly, capsicum plants grown under mulch had significantly higher number of leaves in comparison to control plants, however, those under black plastic mulch had the highest number of leaves (Thwe, 2020).

Indulekha and Thomas (2018) stated that mulching with organic materials improved the number of leaves in turmeric plants grown in different seasons. Similarly, mulching positively influenced the number of branches in broccoli plants grown with mulch. Plastic coloured mulches increased the average number of leaves in comparison to the control in an multi season experiment (Goswami & Saha, 2006). Black plastic mulch outperformed blue, white, green, white and red plastic mulches (Khater et al., 2020). Lasmini et al. (2019) stated that mulching improved the number of leaves in shallots grown under dry land conditions. Lehar et al. (2017) reported higher leaf numbers in potato crop grown under straw mulch compared to the crop grown under silver plastic mulch and the control. Similarly, mulching significantly increased the number of leaves in strawberry plants (Bakshi, Bhat, Wali, Sharma, & Iqbal, 2014). Furthermore, mulching improved the number of leaves in sweet pepper plants in comparison to the control (Arogundade et al., 2019).

Ban, Žanić, Dumičić, Čuljak, and Ban (2009) reported an increased number of leaves in watermelons grown under clear plastic films in comparison to semi-transparent and reflective mulches in separate locations over three years. Chattha and Hayat (2005) stated that organic mulches improved the number of leaves in tomato plants in comparison to inorganic mulches and the control. Moursy et al. (2015) stated that mulching produced a higher number of leaves and branches in tomatoes with transparent and black polyethylene mulches producing the highest number of leaves and branches, which was very apparent from 60 days after transplanting. Nylon mulch increased the number of leaves in cucumber plants grown under black and white plastic mulches. However, white nylon mulch produced the highest leaf number (Babatunde et al., 2020).

2.17 Effect of mulching on leaf size.

The effect of mulching on leaf size in vegetables is well documented. It was reported that mulching improved leaf length in garlic plants. A Garlic crop grown under mulch had significantly longer leaves than control plants. The longest leaf length was obtained from the plot with polyethylene mulch, though there were no significant differences to grown under straw mulch (Gessesew & Tsion, 2017). Leaf area in tomatoes was highly improved by the application of organic mulches (Kayum et al., 2008). Sharma and Sharma (2003) stated that mulching improved leaf area in strawberries. Adnan et al. (2017) reported significantly larger leaf area in strawberry plants grown under mulch.

Moniruzzaman (2006) reported improved leaf size in lettuce plants grown under mulch compared to control. Similarly, Casierra-Posada, Fonseca, and Vaughan (2011) reported that different mulch colours increased leaf area in strawberry plants. Mulching significantly increased leaf area in different lettuce varieties (Saleh et al., 2009). Basil plants grown under mulch had over 40% improvement in leaf area (Nejatzadeh-Barandozi, 2020). Kirnak and Demirtas (2006) stated that mulching with plastic and straw greatly improved leaf area in cucumbers compared to the un-mulched ones. Irrigated watermelons grown under mulch had their leaf area greatly improved by the interaction of mulching and irrigation. Mulching significantly increased leaf area in two hot pepper varieties, with the best results being produced by black plastic mulch, which was better than clear plastic mulch (Iqbal et al., 2009).

Priyamvada et al. (2012) reported larger leaf area in strawberry plants grown under different mulches in relation to the control. Likewise, Acharyya et al. (2020) stated that organic mulches improved leaf length and width in table beets grown under different organic mulches. Mulching with polyethylene produced lager leaf size in chillies than the control (Ahmad et al., 2011). Leaf size in cantaloupe was highly improved by mulch application as compared to the control (Sadek et al., 2019).

Kushwah et al. (2013) reported increased leaf area in ginger plants grown under different mulches. Similarly, mulching maximized leaf area in ginger crops, with some mulch materials outperforming others. Coconut leaf mulch produced maximum leaf area in an experiment that was conducted to assess the impact of mulching on the yield of ginger (Thankamani et al., 2016). Biodegradable mulches significantly increased leaf area in tomatoes grown under both polyethylene and biodegradable mulches. The increase in leaf area in biodegradable mulch grown tomatoes was attributed to the improved soil temperature (Alamro et al., 2019). Lasmini et al. (2019) reported an improved leaf area in shallot plants ground under different mulches in dry land conditions. Lehar et al. (2017) stated that rice straw mulch increased leaf size in potatoes in comparison to silver, black plastic mulch and control.

López-Tolentino et al. (2017) stated that plastic and degradable plastic mulches improved leaf area in cucumber plants grown in different areas. Chattha and Hayat (2005) reported that mulching with straw produced the highest leaf area in leaves of tomatoes grown under organic and plastic mulches. Ruíz-Machuca et al. (2015) stated that coloured plastic mulches improved leaf area in potatoes compared to the non-mulched control. Babatunde et al. (2020) stated that coloured plastic mulches improved leaf area in cucumber leaves in comparison to their control. Teasdale and Abdul-Baki (1995) reported that plastic mulches significantly improved leaf area in tomatoes grown under both plastic and living mulches.

2.18 Effect of mulching on leaf and root fresh weights.

The effect of mulching on fresh weight in plants is well documented. Farhadi, Akbari, and Mosharaf (2002) stated that fresh weight of leaves in watermelons was highly improved due to the application of mulch compared to those grown in bare soil. Fresh weight of strawberry plants grown under mulch in various growing conditions was significantly higher compared to control (Pandey et al., 2015). Moniruzzaman (2006) stated that mulching produced higher fresh weight due to increased canopy width and leaf length. The increase in leaf fresh weight was attributed to the possibility of reduced nutrient loss in mulched plots. Saleh et al. (2009) stated that mulching with black plastic increased leaf fresh weight in lettuce plants. Fresh weight in basil was significantly improved by mulching and the interaction of mulching and irrigation (Nejatzadeh-Barandozi, 2020).

Mulching improved plant biomass in zucchini squash (Summers, Mitchell, & Stapleton, 2004). Similarly, mulching improved the fresh weight of bulbs in garlic varieties grown under both organic and inorganic mulches (Haque et al., 2003). Onion shoot and bulb fresh weights were highly improved by different polyethylene mulches (Sarkar et al., 2019). Gordon et al. (2010) stated that coloured plastic mulches improved okra fresh weight in comparison to the control. Subrahmaniyan and Zhou (2008) stated that mulching with degradable and polyethylene films increased the mean fresh weight of rapeseed in comparison to un-mulched control. The results were attributed to the improved temperature which protected the crop from cold injury, thus improving mean fresh weight.

Sadek et al. (2019) reported that different organic mulches increased the mean plant fresh weight of cantaloupe plants grown over two seasons. Likewise, mulching with different organic materials significantly increased the mean fresh weight in both carrot roots and leaves grown organically. The increase in leaf and root fresh weights was attributed to the improved moisture content in mulched plots (Hasan et al., 2018). Fresh weight of capsicums was significantly improved by the application of mulch from 98 to 112 days after sowing (Thwe, 2020). Lasmini et al. (2019) reported improved fresh weight of shoots in shallots grown under dry land conditions. Fresh weight was greatly improved by the application of mulches in different varieties of cauliflower. The results were attributed to less weeds in mulched plots as well as high hydrothermal regimes which improved growth (Kumar et al., 2019).

Khater et al. (2020) stated that mulching increased both fresh shoot and root weights in broccoli. The control had the lowest fresh weights. A positive impact of mulching on shoot fresh weight was reported in tomato plants grown under biodegradable plastic mulches. Furthermore, mulching produced higher fresh weight of tomato plants grown in different years, with the control producing the least shoot fresh weight. The results were attributed to improved soil moisture. The straw mulch produced the highest fresh weight at 120 days after transplanting (Moursy et al., 2015).

2.19 Effect of mulching on leaf and root dry weights.

Alamro et al. (2019) reported improved dry shoot weight in tomatoes grown under biodegradable mulches in comparison to those that were grown under polyethylene mulch and control. Similarly, mulching with straw in potatoes gave better results compared to plastic mulch and control. Potatoes grown under organic mulch had significantly higher dried weight (Lehar et al., 2017). Likewise, degradable and plastic mulches improved shoot dry weight in cucumbers in comparison to the control (López-Tolentino et al., 2017). Comparably, coloured plastic mulches improved dry weight in potato plants, the control had the lowest plant dry weight (Ruíz-Machuca et al., 2015).

Mulching significantly increased the mean dry weight of tomato plants grown in two different years, with the straw mulch producing the highest plant fresh weight in both years. (Moursy et al., 2015). Hasan et al. (2018) reported improved dry weights in both leaves and roots of carrots grown under organic mulch. Mulching improved maize dry weight in an experiment evaluating the effect of organic mulches on maize performance.

Grazing vetch mulch produced superior results in comparison to forage pea mulch (Murungu et al., 2011). Andersen et al. (2012) reported improved dry weight in tomato plants grown under plastic and reflective mulches with the control having the lowest dry weights. Plastic mulch improved dry weight in tomato plants grown under plastic and living mulches. The results were attributed to improved soil temperature which promoted faster growth (Teasdale & Abdul-Baki, 1995). Dry shoot and root weights were improved in broccoli plants grown under mulch (Khater et al., 2020).

Kayum et al. (2008) reported significantly higher weight of dry leaves of tomato plants in plots which had organic mulches. Nejatzadeh-Barandozi (2020) reported that mulching improved dry weight in basil plants compared to control. Similarly, mulching improved bulb dry weight by over 45% in onions compared to control (Abdel, 2006). Swiss chard grown with mulch in both spring and winter had significantly improved dry weight (Zhang et al., 2009). Straw mulch greatly improved dry weight in turnips (Manrique, Montemayor, Cave, Skvarch, & Smith, 2010). Summers et al. (2004) stated that mulching significantly increased plant dry weight per plant compared to plants grown in bare soil.

Natural and synthetic mulches greatly increased the individual dry weight of onion bulbs in a trial, maximum dry weight was obtained from plants mulched with water hyacinth, while black plastic mulch produced the lowest dry weight (Haque et al., 2003). Furthermore, mulching improved onion dry shoot and bulb weights by 34 and 56% respectively in comparison to control (Sarkar et al., 2019). Sadek et al. (2019) reported that different organic mulches increased the plant dry weight of cantaloupe plants.

2.20 Effect of mulching on root size

Tomato plants grown under different mulches had improved root length. Red clover mulch outperformed the other mulches and the results were attributed to improved moisture retention (Bender et al., 2008). Yan et al. (2018) reported improved root growth in rice grown under mulch and Islam et al. (2002) observed a significant variation in root length of onions grown under mulch. The longest root length was observed in plots which had straw mulch, with the shortest in plots which had polyethylene mulch. The results were attributed to higher moisture retention and increased soil temperature.

Mulching increased bulb size by over 70% in onions grown under irrigation in relation to control plants (Abdel, 2006). Acharyya et al. (2020) stated that organic mulches improved root size in beetroot. Both root length and diameter were significantly higher in all mulched crop relative to the control. Mulching with organic and inorganic materials significantly improved the diameter of garlic bulbs, with some variations among the treatments. The control had the smallest bulb diameter. Sarkar et al. (2019) stated that mulching with coloured polyethylene mulches improved bulb length and diameter of onions in relation to those that were grown under bare soil. Similarly, mulching increased the mean root diameter in organically grown carrots (Hasan et al., 2018).

Plastic mulches significantly improved early root length in tomato plants in comparison to hairy vetch mulch and the control (Teasdale & Abdul-Baki, 1995). Mulching increased the root length in dry land grown shallots. Furthermore, it was observed that root length increased with an increase in soil moisture content. Similarly, straw mulch increased bulb diameter in dry land grown shallots with the control having the least increase in bulb diameter (Lasmini et al., 2019). Bharati et al. (2020) stated that mulching significantly increased the diameter of potato tubers in comparison to control. Islam et al. (2002) found that mulching increased bulb size in onions. Acharyya et al. (2020) found that mulching increased root size of beetroot.

2.21 Effect of mulching on beetroot and root crop yield

The effect of mulching on yield in beetroot and root crops is well documented. An experiment evaluating the effect of mustard mulch, straw mulch and prewinter plough (conventional tillage) on yield and root quality of two sugar beet cultivars found that mulches increased sugar beet root yield by over 9% compared to conventional tillage (Artyszak, Gozdowski, & Kucińska, 2014). Mulching improved late season potato cultivars yield due to reduced weed infestation in mulched plots compared to mechanically weeded plots (Genger, Rouse, & Charkowski, 2018). An experiment evaluating the impact of two organic mulches on weed infestation and yield of beetroot found that mulching improved yield by over 7 times compared to the control due to weed absence in mulched plots (Yordanova & Gerasimova, 2016). Olfati, Peyvast, and Nosrati-Rad (2008) reported significantly higher yield in carrots grown under organic mulches in comparison to un-mulched control.

Gross yield of carrots per hectare was significantly improved by the application of organic mulches, with hyacinth mulch producing the highest yield (Hasan et al., 2018). Mulching with different materials improved rhizome yield of ginger crops grown over successive seasons Kushwah et al. (2013). Similarly, mulching increased marketable yield and bulb weight, in onions grown over four seasons in an experiment evaluating the response of short-day onions to mulch application in a semitropical environment (Vavrina & Roka, 2000). Lasmini et al. (2019) stated that mulching improved yield of shallots in comparison to control. Lehar et al. (2017) reported that organic mulches significantly improved potato tuber yield in comparison to plastic mulches in an experiment which was conducted to evaluate the effect of both organic and plastic mulches.

Mulching with black polyethylene and straw significantly increased sugar beet yield in an experiment conducted in different seasons in Pakistan. Based on the results, mulching increased storage root yield by over 12% in comparison to the control. However, black plastic film mulch outperformed straw mulch (Latif, Ajmal, & Ahmad, 2018). Carvalho, Ribeiro, and Gomes (2018) stated that mulching significantly increased marketable yield of onion which was grown under different irrigation regimes in comparison to the control. Rahman, Islam, Al Mamun, Rahman, and Ashraf (2018) stated that mulching significantly increased total marketable yield in carrots. Similarly, Solaiman, Hasanuzzaman, and Uddain (2008) reported of improved yield in turnips which were grown under mulch in comparison to the non-mulched control. Carmichael et al. (2012) stated that grass mulch increased radish yield in comparison to bare soil. (Nwosisi, Nandwani, & Pokharel, 2017) stated that mulching improved the total marketable yield of sweet potato roots as compared to control.

Sangakkara, Attanayake, Gajanayake, and Bandaranayake (2004) reported improved sweetpotato and cassava yields due to application of mulch. They found that mulch improved moisture conservation which enhanced growth and resulted in an increased yield in both crops. Sanyal and Dhar (2006) stated that mulching significantly increased the total rhizome yield in turmeric in comparison to non-mulched control in an experiment assessing the impact of mulching, nitrogen and potassium on turmeric growth, yield and quality. Ahmed, Mahmud, Hossain, Zaman, and Chandra (2017) stated that different mulch materials improved total tuber yield of potatoes in comparison to the non-mulched control. Similarly, Weerakoon et al. (2017) found that organic mulches significantly improved onion bulb yield. Woldetsadik, Gertsson, and Ascard (2003) stated that mulching improved yield in shallots in comparison to control. Olfati et al. (2008) reported significantly higher yield in carrots grown under organic mulches in comparison to non-mulched control.

Mulching increased yield in potatoes in comparison to the control (Mahmood, Farooq, Hussain, & Sher, 2002). Similarly, Momirovic, Mišovic, and Brocic (1996) reported that organic mulches improved yield in potato seed crop from about 40t/ha to 50t/ha. Ruiz, Hernandez, Castilla, and Romero (1999) reported that mulching improved total yield in potato tubers compared with the control. Wang, Feng, Hou, Kang, and Han (2009) found that mulching increased tuber yield in comparison to local average yield. The results were attributed to improved water use efficiency in mulched plots. Barakat, Abd El-Mageed, Elsayed, and Semida (2020) reported significantly higher yield in potatoes grown under mulch.

Riley, Løes, Hansen, and Dragland (2003) reported improved yield in beets grown under chopped grass and clover mulch as surface mulches in a 3 year long experiment. However, it was observed that repeated applications of mulch material produced more yield in all three years. Rani, Malek, and Robbani (2016) conducted an experiment assessing the impact of organic manure and mulches on growth and yield of carrots. Results showed that mulching improved yield in all the plots. Carvalho, Gomes, et al. (2018) conducted an experiment with the aim of evaluating carrot yield and water use efficiency under different mulches. Results showed that mulching significantly improved yield in carrots. Similarly, Jaysawal (2018) reported of improved carrot yield in an experiment that was conducted to evaluate the response of carrot to application of organic and inorganic mulches. Results showed no significant differences between the mulches on carrot yield.

Biswas (2018) carried out an experiment on the effect of organic manure and mulching on carrot yield. The results showed that mulching significantly increased all yield parameters in carrots including marketable root yield. Similarly, plastic mulches increased yield in sweet potatoes in an experiment conducted in different locations in New Zealand assessing the impact of plastic mulches on autumn grown sweet potatoes (Shaw & James, 2007). Šlosár, Mezeyová, Hegedűsová, and Golian (2016) reported that mulching improved the total marketable yield and reduced non-marketable yield in sweet potatoes. An experiment that was conducted to evaluate different organic mulches on growth and yield of ginger found that mulching significantly improved yield in comparison to control (Singh et al., 2014).

2.22 Effect of mulching on beetroot and root crop quality

Mulching significantly improved quality in potatoes as evidenced by higher vitamin C content in mulched plots in comparison to the crop grown on bare soil (Caruso et al., 2013). Additionally, the mulched crop, grown in a summer-autumn growing season, outperformed the crop grown in a winter-spring season. The results were attributed to reduced soil temperature by the mulch in summer (Caruso et al., 2013). Similarly, Olfati et al. (2008) reported significant quality improvement in carrots grown under cover in comparison to uncovered crop. Ahmed et al. (2017) stated that mulching significantly increased quality in potato tubers as evidenced by higher dry matter content in mulched potatoes. Similarly, Solaiman et al. (2008) reported of a significant dry matter content in turnip roots which were grown under mulch.

Rahman et al. (2018) reported of significantly higher dry matter content in carrot root which were grown under compared to non-control. Mulching improved quality in potato tubers (Li et al., 2021). The results were attributed to improved water efficiency in mulched plots. Moursy, El-Kady, Hamed, Ibrahim, and Emara (2021) reported improved sugar beet quality in mulched plots in comparison to non-mulched control. Sekhon et al. (2020) reported improved quality in potato tubers raised on mulched plots. Hou et al. (2019) reported that mulching improved starch in storage roots of sweet potato cultivars grown in summer in north China.

Shaw and James (2007) carried out an experiment evaluating the impact of different mulch materials on soil temperature and growth in sweet potatoes. The results showed that mulching improved quality in sweet potato storage roots, as evidenced by higher dry matter content in comparison to control. Similarly, Šlosár et al. (2016) who worked with three sweet potato varieties in an experiment evaluating the impact of mulches on growth, yield and quality, found that mulching significantly improved all the quality parameters, including vitamin C content and carotenoid content.

2.23 Effects of mulching on economic returns

Mulching has been highly associated with higher net returns in several crops. Mulching enhances crop yield and conserves soil moisture, which saves on irrigation water, thus increasing profit. Furthermore, organic mulches release important nutrients into the soil, thus reducing fertilizer usage and costs. Additionally, as mulches reduce weeds, herbicide usage is minimized, contributing to a lower production cost. However, several factors contribute to profitability of mulches viz. cost of mulch material and costs associated with their removal (Jalota, Khera, Arora, & Beri, 2007). Organic mulches produced a maximum benefit-cost ratio in tomato plants grown with both organic and inorganic mulches, the un-mulched control proved lowest (Chattha & Hayat, 2005).

An experiment evaluating the effect of organic mulches on cantaloupe in a controlled environment found that straw mulch produced the highest net return. However, other organic mulches still produced higher returns than the control (Sadek et al., 2019). Water hyacinth mulch increased the net profit in organically grown carrots due to the increase in yield (Hasan et al., 2018). Kushwah et al. (2013) stated that mulching significantly increased the net return in ginger farming in comparison to the control. Organic mulches produced more net return than plastic mulches. This was due to the lower cost of production incurred by the organic mulches.

Mulching with organic and coloured plastic viz. yellow, pink, blue, red, black and silver, increased net return in watermelons in comparison to the control. The silver-coloured plastic mulch produced the highest net return, with the least net return in control (Rao, Bajpai, Gangwar, Chourasia, & Soni, 2017). Mulching increased net return in a capsicum crop grown utilising drip irrigation (Paul et al., 2013). Vavrina and Roka (2000) stated that the use of plastic mulches in sweet onion production has a great impact on net return, study showed that higher net return was obtained from the mulched crop than the control crop. Similarly, Kumar (2015b) stated that mulching increased net return in a maize crop grown in different seasons to evaluate the effect of mulching and farmyard manure on productivity and quality. Different organic mulches increased profit in okra grown in two successive seasons in comparison to the control. Mulch from panicum (Panicum grass) produced the maximum net return compared to other mulches (Adekiya et al., 2017).

Black plastic mulch increased total profit in chilli plants grown under coloured plastic mulches to evaluate the effect on growth, yield and economic return (Thwe, 2020). Mulching improved profit in maize as a result of improved yields in comparison to the control (Murungu et al., 2011). Mulching significantly improved net profit in okra plants, with plastic mulches outperforming organic mulches (Bhutia et al., 2017). Similarly, mulching with straw produced the highest revenue in tomatoes grown in two different years. The un-mulched plot had the lowest net revenue (Moursy et al., 2015). Mulching with both plastic and organic material increased total net return in comparison to non-mulched control. However, plastic mulches had higher production costs. (Kumar et al., 2019).

Mulching improved the total profit in a cauliflower crop. The increased net profit was attributed to the higher moisture retention observed in plots with mulches (Job, 2018). Similarly, the use of mulches in summer squash significantly improved the net revenue in comparison to control (Bhatt, Maurya, & Singh, 2016). Chaurasia and Sachan (2020) stated that mulching increased net returns in summer squash in an experiment using both organic and inorganic mulches. However, black plastic mulch was found to be more economical than other mulch types. Kumar (2014) reported of increased gross and net returns in Eureka lemons grown under different organic and plastic mulches. The improved cost-benefit ratio was attributed to higher early and total yield. Nair (2018) stated that both gross and net returns were significantly improved by the application of organic and plastic mulches.

2.24 Concluding statement

It is apparent from the wide range of published research relating to mulches in vegetable production that mulches in all forms offer considerable advantage for managers in production and economically. The improved growth rate generally leads to a shorter production period overall for short term vegetables such as beetroot. This frees up land for the next cycle of crops and reduces inputs to the whole cropping cycle. On the negative side, there is the need to either dispose of plastic mulches, which are also costly; or to reapply organic mulches as they gradually break down into the soil. The literature also lacks published research on mulches in Malawi or about production systems in Malawi. This emphasises the benefit of this trial for Malawian farmers.

CHAPTER 3

Materials and methods

3.1 Introduction

This chapter describes how and where the experiment was conducted. It elucidates the conditions of the experimental sites and the experimental design. It also explains how the crops were produced and managed using standard systems applied by Malawian farmers. Finally, it describes the data collection and recording methodology.

3.2 Experimental site

The trial was undertaken on farmers land near Bvumbwe which was independent of any research station or facility, hence traditional growing approaches were applied. Bvumbwe is in the southern part of Malawi (see Figure 4), 13 km southeast of Blantyre city, at 15 55’S 35 04’E. It is adjacent to the main shire valley (APPSA, 2012). The local climate is typical of the climatic conditions that characterize the entire nation. The area receives an average of 1200mm of annual rainfall which occurs between December and April. Average temperature ranges from 15 to 22ºC (APPSA, 2012).

The soils around Bvumbwe are generally fertile. The soil pH ranges from 5.3 to 5.8 in the topsoil and 5.2 to 6.0 in the subsoil. Soil organic carbon for both soil depths ranges from 0.8 to 1.7%. Soil organic matter is in the range of 1.44 to 3.0% at both soil depths. Nitrogen is available in levels between 0.04 and 0.08%. Some areas surrounding Bvumbwe have low potassium levels of 63mg/kg, with other areas having as high as 236.92mg/kg. Most areas have relatively high sand proportions ranging from 36.42 to 44.42%, while clay and silt values range between 20 to 40% at both soil depths (Njoloma, Sileshi, Sosola, Nalivata, & Nyoka, 2016).

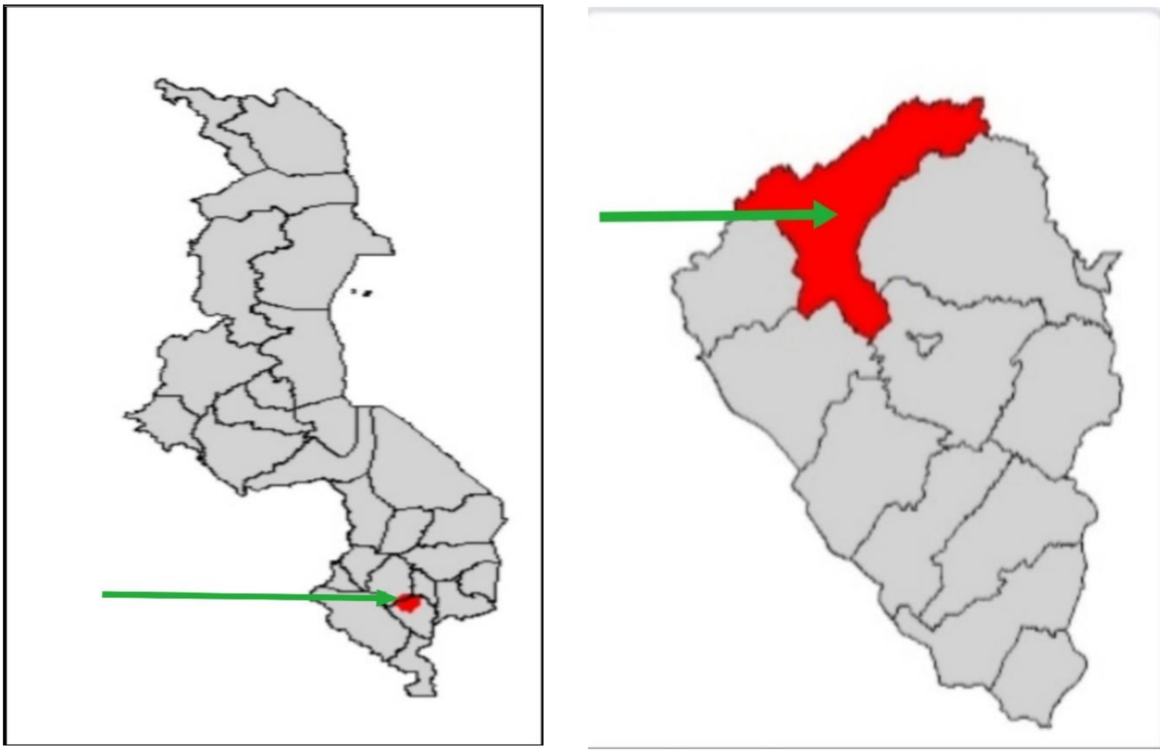

Figure 6: Map of Malawi (left) showing the experimental site; Bvumbwe (red) and extracted map (right) of Thyolo district showing Bvumbwe (red).

(Source: gadm.org/maps/MWI/thyolo/tabvumbwe.html).

3.3 Experimental details

The experiment was laid under split-plot with a randomized complete block design and three replicates. Two factors measured were mulching and variety. Mulching treatments evaluated were straw mulch and compost mulch. The control had beetroot plants grown on bare soil. Varieties evaluated in this trial were Detroit dark red, Crimson globe and Globe dark red (variety choice was restricted to what was available in Malawi). The main plots consisted of the mulching treatments while the subplots had the three beetroot cultivars. Most vegetable production in Malawi is done by small holding farmers who cannot afford good irrigation equipment such as water pumping engines, treadle pumps, solar powered pumps or wind mills to irrigate their crops hence this experiment used watering cans which are typically used by most farmers. Additionally, sun drying was used instead of ovens which is the typical method used among small holding farmers.

3.4 Overview of beetroot cultivars tested in this trial.

3.4.1 Detroit dark red

Detroit dark red (Figure 7) is considered one of the best beetroot cultivars as it well suited in many climates. It grows well in many soil types and tolerates both heat and cold. The storage roots are perfectly smooth and uniform, the flesh is generally red with light red zoning while the skin has a deep red colour. Detroit dark red leaves are generally medium to tall with bright green leaves which have a maroon shade. The variety takes about 2 to 3 months to mature. Additionally, it is relatively tolerant to bolting and resistant to several diseases such as *Cercospora* leaf spot and other beetroot diseases. Detroit dark red is well suited to both processing and fresh markets and well suited to Malawi production (Goldman et al., 2008).

Figure 7: Detroit dark red variety

(Source: https://gardenerspath.com/plants/vegetables/best-beet-varieties/)

3.4.2 Crimson globe

Crimson globe (Figure 8) is a reliable variety which is well suited to warm and cool growing conditions with some degree of tolerance to heat stress. The storage roots are generally globular to flattened with medium red little shoulders. The tops are medium to tall with larger bright green leaves with a maroon shade. It is a high yielding variety which can be harvested after 2 to 3 months. Crimson globe is well suited to processing and fresh markets (Sakata, 2014) and suits the climatic conditions in Malawi well.

Figure 8: Crimson globe variety

(Source: Sakata, 2014)

3.4.3 Globe dark red

Globe dark red (Figure 9) is a high yielding variety which is well suited to warm season climates. It is an early maturing variety which takes about 65 to 75 days to mature. The storage roots are generally uniform flat rounded with a slender attractive taproot. The storage root has a dark red colour with a refined colour. Moreover, the storage roots can retain their colour even at full maturity. The beet tops are green in colour and medium in size. When it comes to growing conditions, Globe dark red variety can tolerate adverse weather conditions such as heat, which makes it a high performer in the field. Furthermore, globe dark red can grow up to 30cm and it performs well in both processing and fresh market. Its relatively vigorous, a characteristic which is responsible for its high tolerance to diseases (Neelwarne & Halagur, 2013). This variety is highly suitable to Malawi production.

Figure 9: Globe dark red variety

(Source: Neelwarne & Halagur, 2013)

3.5 Cultural practices

3.5.1 Land preparation

The land was properly dug following Malawi farming practises using hand hoes to ensure that the previous crop was eliminated. Then the field was left for some days to allow the removed crop to dry out. A week before transplanting, beds of 1m by 0.5m ($0.5m^2$) were prepared in line with the experimental layout. There were 27 beds which covered a total area of $34m^2$ (see Figure10).

Figure 10: The experimental plot ready for transplanting

3.5.2 Raising the seedlings

The nursery beds were thoroughly prepared to ensure fine tilth of the soil ideal for seed germination. Seeds were sown according to variety at a depth of 1-1.5 cm. Before sowing 100g of nitrogen fertilizer was applied per$1m^2$ of each seedbed to facilitate the growth of seedlings. Three beetroot varieties, Detroit dark red, Crimson globe and Globe dark red were sown on 10th of June 2020 in drills 5cm apart. Watering was done at planting and after every 3 days to maintain adequate moisture until the seedlings were fully emerged.

3.5.3 Transplanting and mulch application

Transplanting was done on the 15th July 2020 when the seedlings were 5 weeks old. Mulches were added on the 22nd of July, a week after transplanting to ensure all transplanted seedlings had established. Figure 11: Seedling transplanting (left) and mulch application (right) shows transplanting and mulch application a week after transplanting.

 

Figure 11: Seedling transplanting (left) and mulch application (right)

3.5.4 Fertilizer application

Fertilizer application was done on the day of transplanting at the rate of 150 kg N/ha, 65 kg P/ha and 32 kg K/ha with NPK (23:10:5) fertilizer.

3.5.5 Irrigation

The experimental block was irrigated twice weekly on a 3-day interval to maintain adequate moisture. Watering cans were used for irrigation.

3.5.6 Crop protection

Hand weeding was done when necessary to keep the crop from weeds to ensure that any competition between the crop and weeds was eliminated. Crops were monitored twice weekly for any signs of pests or disease, however there were no plant health factors requiring management. Beetroot had not been grown in this field before.

3.6 Data collection

Data were collected on plant height, the number of leaves per plant, length and width of two leaves per plant, leaf fresh weight, root dry weight, root size, marketable and non-marketable yield dry matter content, and economic return from each treatment was calculated following harvest.

3.6.1 Growth parameters

3.6.1.1 Plant height

Eight plants from the net plot were measured from each treatment. Plant height was measured from the ground to the tip of the plant using a ruler. Figure 12 shows the investigator collecting data on plant height.

Figure 12: Measuring planting height using a ruler

3.6.1.2 Leaf number

The number of leaves from each plant in the net plot was counted and recorded weekly

3.6.1.3 Leaf size

Two leaves from four randomly selected plants from the net plot were marked and had their length and width measured weekly throughout the growing period.

3.6.1.4 Leaf fresh weight

Following harvest, leaves from the plants were separated from the storage root and weighed on a scale and their fresh weight recorded in grams. Leaves were cut at approximately 1cm from the top of the swollen root to minimise root damage. Figure 13: Measuring leaf fresh weight from a selected plant 13 shows the fresh leaves separated for weighing from the root.

Figure 13: Measuring leaf fresh weight from a selected plant

3.6.1.5 Leaf dry weight

Leaves from the plants in the net plot which had their fresh weight weighed and recorded were sun-dried for seven days and weighed. Then the leaves were further dried and weighed again until the dry weight remained static. This was done to ensure that the leaves have completely dried out in the absence of access to drying ovens. Figure 14: Measuring leaf dry weight. 14 shows leaf dry weight measurement.

Figure 14: Measuring leaf dry weight.

3.6.1.6 Root fresh weight

The root portion of the plant or beetroot was weighed on a scale and had their fresh weight recorded in grams. Figure 15: Measuring root fresh weight shows measurement of root fresh weight.

Figure 15: Measuring root fresh weight

3.6.1.7 Root dry weight

Once beetroot from the net plot which had their fresh weight recorded, they were first cut into pieces to hasten the drying process (again in the absence of access to drying ovens) and then they were sun-dried for seven days and weighed. Then the roots were further dried and weighed again until the weight remained unchanged. This was done to ensure that the roots had completely dried. The root dry weight was recorded in grams. Figure 16: Beetroot freshly cut slices before drying (left) and after drying (right) 16 shows beetroot freshly cut slices before drying (left) and after drying (right).

Figure 16: Beetroot freshly cut slices before drying (left) and after drying (right)

3.6.1.8 Marketable and unmarketable yield

Following the recording of gross yield per plant, the roots were separated into marketable and non-marketable depending on the size of the roots for sale at the local market. The marketable yield was found by subtracting the non-marketable yield (cracked and branched beets) from the gross yield.

3.6.1.9 Dry matter content

The sun-dried root weight was subtracted from the fresh root weight and expressed in percentage to find the dry matter content percentage.

3.6.1.10 Economic return/ Net profit

Economic analysis was carried out to assess if mulching affected the profitability of beetroot crop in Malawi. Total production cost and total revenue per hectare were determined, from which net profit (NT) was computed by subtracting total expenses (TE) from total revenue (TR). NT = TR – TE. The total production cost was determined by adding together the total inputs and labour costs incurred from the different treatments.

CHAPTER 4

Results

4.1 Results

This chapter presents the results of the effect of mulching with organic materials on growth, yield and quality of three beetroot varieties grown in Malawi. Results presented in this chapter include growth, yield and quality parameters. Climate data was gained for the region during the period of the trial and the rainfall was minimal throughout the period with the month of July receiving double the amount of the rest of the months for the trial period (see Table 1). Additionally, both maximum and minimum temperatures were within the optimum temperature range of beetroot production. This is presented for supporting the environmental conditions the trial was subject to, especially as it was the dry season. The crops were supported by irrigation every 3 days during establishment and maturity.

Table 1: Bvumbwe Climate data June-September 2020

Month (2020)	**Mean monthly rainfall (mm)**	**Mean monthly Temperature**	
		Maximum	**Minimum**
June	5.4	20.6	12.2
July	11.5	23.1	19.4
August	2	24.1	13.4
September	0.1	26.0	14.8

Source: Meteorological department
Bvumbwe research station
Thyolo, Malawi.

4.1.1 Plant height.

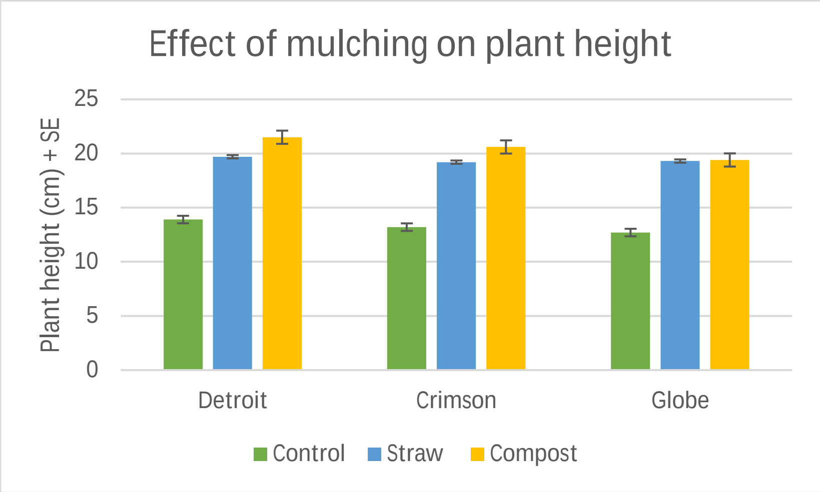

Figure 17: Effect of organic mulches on plant height of three beetroot varieties

Figure 17: Effect of organic mulches on plant height of three beetroot varieties 17 shows the effect of organic mulch on beet plant height. This was recorded for the entire period of plant growth starting one week after mulch application. The mulch treatments produced significantly higher plant height in comparison to the control. This trend was similar in all the varieties. Detroit dark red variety had a mean height of 13.9 cm under the control and was statistically lower than 19.7 and 21.5 cm, the mean heights for the same variety for straw and compost mulches respectively. It was observed that compost mulch was superior to straw mulch in this variety. Similarly, Crimson globe cultivar had a mean height of 13.2 cm under the control and was statistically lower than 19.2 and 20.6 cm for the straw and compost mulches respectively. Comparatively, Globe dark red showed a similar trend in plant height for the control, straw and compost mulches. The mean height for the control was 12.7 cm while that of straw and compost mulches were 19.3 and 19.4 cm respectively. Compost mulch outperformed straw mulch. The differences in plant height were obvious from the second week after the first day of data collection and remained consistent throughout the growing period. Furthermore, Detroit dark red variety was superior to other varieties as it had the maximum mean height in all the treatments. However, there were no significant differences among the varieties.

4.1.2 Number of leaves

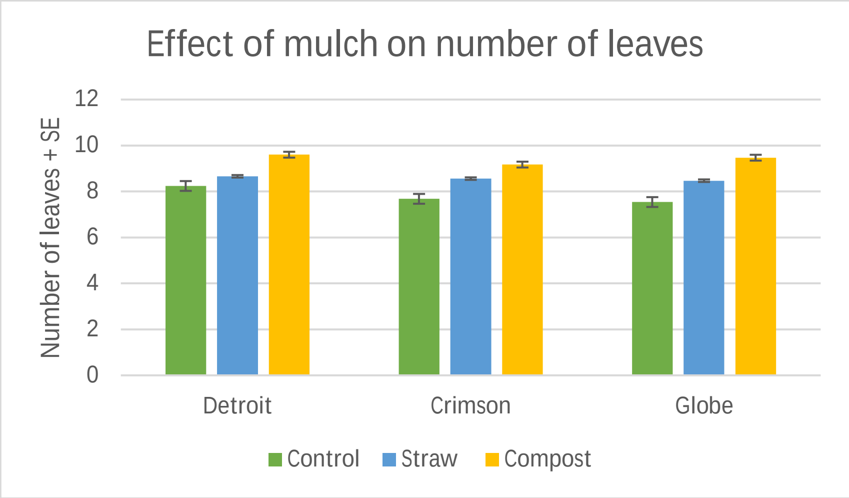

Figure 18: Effect of mulching on the number of leaves for three beetroot varieties

Figure 18: Effect of mulching on the number of leaves for three beetroot varieties 18 shows the mean leaf numbers of all the three varieties grown under the control, straw and compost mulches. According to the results, there were no significant differences observed between the mulch treatments on the number of leaves for the first two weeks after mulch application. Differences were observed from week three after mulch application and a significant effect on the number of leaves was noted from the 4th week until the end of the growing period. The effect of the mulch treatments was similar in all the three varieties with the controls having the lowest mean leaf numbers. Detroit dark red had mean leaf numbers of 8.24, 8.66 and 9.6 for the control, straw mulch and compost mulch respectively. Although there were no major differences between straw and compost mulches, compost mulch slightly increased the average number of leaves. Similarly, Crimson globe had the lowest mean number of leaves. Both straw and compost increased the average number of leaves in Crimson beets. The average number of leaves were 7.68, 8.56 and 9.17 for the control, straw and compost mulches respectively. Compost mulch, however, outperformed straw mulch as it produced slightly higher leaf numbers. Globe dark red variety had 7.54, 8.47 and 9.47 as the mean number of leaves for the control, straw mulch and compost mulch respectively. Although compost mulch treatment had the maximum mean number of leaves, there were no significant differences among the treatments. However, the control had the least number of leaves. Overall, compost mulch produced superior results over straw mulch in all the three varieties. On the other hand, varieties were similar in their performance as no significant differences were observed

among them. However, Globe dark red had a slightly higher number of leaves compared to the other varieties.

4.1.3 Leaf length and width.

Mulching affected leaf length and width differently in the three beet varieties. There were no significant differences observed from the treatments in all the three varieties for the leaf length and it is assumed much of this relates to the morphological characteristics of each cultivar and as such the leaf length is a better statement on the activity of the plan. The mean leaf lengths for Detroit dark red were 5.9, 6.8 and 6.6 cm for the control, straw mulch and compost mulch respectively. However, straw mulch produced the maximum mean leaf length with the control having the lowest mean leaf length. Crimson globe had 5.7, 5.9 and 6.6 cm as the average leaf lengths for the control, straw mulch and compost mulch respectively. These differences were not significantly different which the case with Detroit dark red variety was also. However, unlike Detroit dark red, which had its maximum leaf length under straw mulch, the highest mean length was obtained from compost mulch. Similarly, Globe dark red had a similar trend to that of Crimson globe. The mean leaf lengths were 5.4, 6.4 and 6.8 cm for the control, straw mulch and compost mulch respectively. However, there were no significant differences among the mulch treatments. Furthermore, varieties were not significantly different from each other concerning the mean leaf length. Overall, both the interaction of days and treatments and days and varieties had no significant effect on the mean leaf length. Compost mulch outperformed straw mulch in Crimson globe and Globe dark red while straw mulch showed superior results in Detroit dark red variety.

On the other hand, leaf width, which started increasing from day 14 after mulch application, was differently affected by mulch application and variety. Detroit dark red had mean widths of 3.8, 3.8 and 3.6cm for the control, straw mulch and compost mulch respectively. The differences among the treatments were not significantly different. However, compost mulch had the lowest mean leaf width. Comparatively, Crimson globe had 3.0, 3.4 and 3.4cm as the average means for the control, straw mulch and compost mulch respectively. Straw and compost mulches had slightly higher means compared to the control. Similarly, Globe dark red had 3.0cm as the mean leaf width for the control which was significantly lower than the means for straw mulch and compost mulch which were 3.4 and 3.7cm respectively. The differences in these two varieties were slightly different with straw mulch and compost outperforming the control. Overall, the interactions of days and treatment, treatment and variety and days and variety had a significant effect on leaf width. On the varieties, compost mulch outperformed straw mulch in all varieties except Detroit dark red which had its maximum mean leaf width under the straw mulch treatment.

4.1.4 Leaf fresh and dry weights

Mulching improved leaf fresh and dry weights in all three varieties of beetroot in comparison to bare soil. These final weights represent the values of mulch over the whole production cycle. The mean leaf fresh weights for Detroit dark red were 42, 69.7 and 68 g for the control, straw mulch and compost mulch respectively. The mean fresh weights for Detroit dark red variety were significantly different at 5% level of significance, with the straw much producing the highest mean fresh weight. Comparatively, the mean fresh weights for Crimson globe were 44, 61 and 72 g for the control, straw mulch and compost mulch respectively. The treatments were found to be significantly different at 5% level of significance with compost mulch producing the maximum leaf fresh weight. Similarly, the means for leaf fresh weight for Globe dark red variety for the control, straw mulch and compost mulch were 38.3, 63 and 73 g respectively. The mulch treatments significantly improved the mean leaf fresh weight for Globe dark red variety. However, compost mulch produced the highest leaf fresh weight. Overall, compost mulch outperformed straw mulch and no differences were observed among the three varieties. However, both the lowest and maximum leaf fresh weights were obtained from Globe dark red.

The effect of mulching on the leaf dry weight was also recorded. Mulching treatments significantly increased dry weights of all three beetroot varieties. The mean dry weights for Detroit dark red were 9.5, 15.7 and 14.3 g for the control, straw mulch and compost mulch respectively. Similarly, the mean dry weights for Crimson globe were improved by the different mulch treatments. The average dry weights were 10, 14.0 and 15.3 g for the control, straw mulch and compost mulch respectively. Likewise, Globe dark red had its dry weight significantly improved by the application of mulch. The average dry weights for this variety were 7.8, 14 and 15.7 g respectively. Generally, mulch treatments improved the mean dry weights in all the three beet varieties. However, compost mulch was superior to straw mulch. There were no significant differences observed among the varieties.

4.1.5 Root fresh and dry weights

Root fresh and dry weights were significantly affected by the application of organic mulches. The fresh weights for Detroit dark red variety were 42, 69.7 and 68 g per plant for the control, straw mulch and compost mulch respectively. Both straw and compost mulches significantly increased the root fresh weight at 5% level of significance. Similarly, mulching significantly increased the root fresh weight in Crimson globe variety. The mean fresh weight for the control was 44g and it was significantly lower than 61 and 72 g, the mean root fresh weights for the straw and compost mulches respectively. The fresh weights for Globe dark red were also greatly affected by the application of mulch. Both straw and compost mulches significantly improved the mean fresh weights at 5% level of significance. The control had the lowest mean fresh weight of 38.3 g, followed by straw mulch which produced a mean root fresh weight of 63 g. Compost mulch had the maximum mean weight of 73 g. In all the three varieties, compost mulch outperformed straw mulch. Both the maximum and minimum fresh weights were obtained from Globe dark red variety. However, there were no significant differences observed among the different varieties on the root fresh weight.

A similar trend was also observed from the root dry weights. The root dry weights for all three varieties were significantly increased at 5% level of significance. The dry weights for Detroit dark red variety were 19.7, 38.3 and 38.4 g for the control, straw mulch and compost mulch respectively. Similarly, mulching significantly increased the mean root dry weight in Crimson globe variety, which were 19.3, 37.7 and 47 g for the control, straw mulch and compost mulch respectively. The mean root dry weights for Globe dark red were also highly affected by the application of mulch. The control had the lowest mean fresh weight of 18 g, followed by straw mulch which produced a mean root fresh weight of 37.8 g. Compost mulch had a mean weight of 45 g. In all three beetroot varieties, compost mulch was superior over straw mulch. The maximum dry weight was obtained from Crimson globe while the minimum dry weight was obtained from Globe dark red. However, there were no significant differences observed among the different varieties on the root dry weight. Once again, the harvested weights of the roots (fresh and dry) represent the final value of the plants from the full production cycle. The improved weights under both mulches for all three varieties indicates a strong trend, which is supported by the 5% levels of significance achieved.

4.1.6 Root diameter

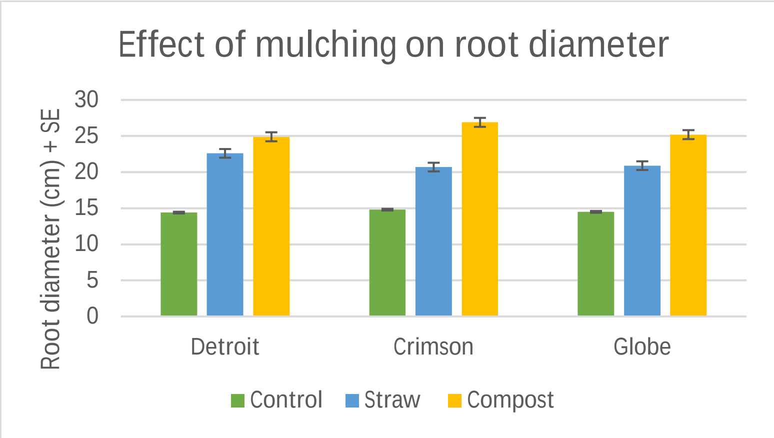

Figure 19: Effect of organic mulches on storage root diameter of three beetroot cultivars

Table 2: Analysis of Variance table showing the differences in beetroot response to the different treatments and varieties for root diameter

	DF	Sum Squares	Mean Squares	F value	Pr (>F)
Treatment	2	1513.76	756.88	262.1633	<2e-16***
Variety	2	4.28	2.14	0.7419	0.4803
Treatment: Variety	4	32.44	8.11	2.8089	0.0328*
Residuals	63	181.88	2.89		

*significant at p< 0.05; ** significant at p< 0.005; ***significant at p< 0.001

Figure 19: Effect of organic mulches on storage root diameter of three beetroot cultivars 19 shows the effect of mulching on storage root diameter in three beetroot varieties. The mulch treatments had a significant effect on the average diameter of the storage roots for

all three beetroot varieties. The mean root diameter for Detroit dark red variety were 14.4, 22.6 and 24.9 cm for the control, straw mulch and compost mulch respectively. Compost mulch produced the maximum root diameter. Similarly, the mean root diameter for Crimson globe were 14.8, 20.7 and 26.9 cm for the control, straw mulch and compost mulch respectively. Both straw and compost mulches significantly increased storage root diameter at 5% level of significance in comparison to the control. However, compost mulch outperformed straw mulch. A similar response was also observed in Globe dark red variety, which had significantly higher root diameter in mulch treatments in comparison to the control. The mean diameters for the storage root were 14.5, 20.9 and 25.2 cm for the control, straw mulch and compost mulch respectively. Overall, compost mulch was superior over straw mulch and no differences were observed among the varieties.

4.1.7 Dry matter content

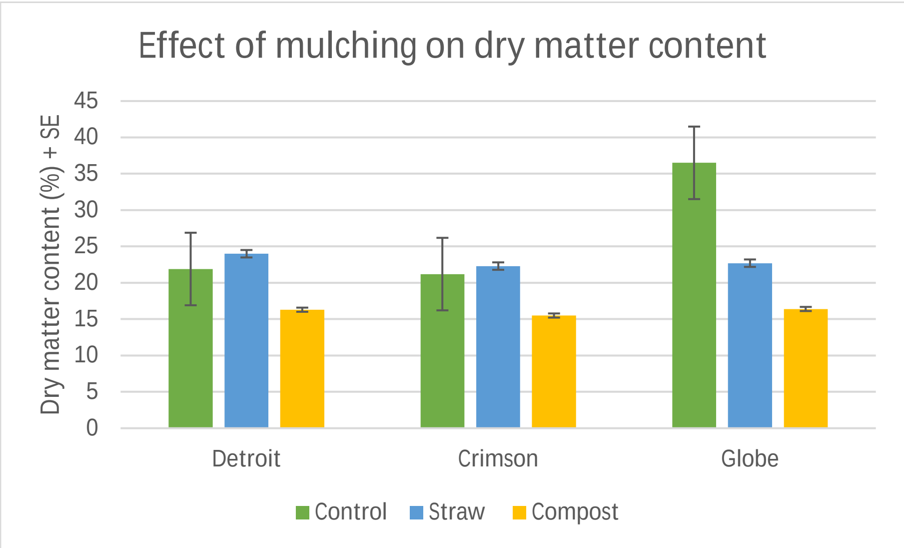

Figure 20: Effect of organic mulches on dry matter content of three beetrootcultivars

Figure 20 indicates the effect of mulching on dry matter content in the three beetroot varieties. The mulch treatments did not have a significant effect on the mean dry matter of all the three varieties. The percentage dry matter contents for Detroit variety were 21.9, 24.0 and 16.3% for the control, straw mulch and compost mulch respectively. Compost mulch had significantly lower mean dry matter content in comparison to the control. The maximum mean dry matter content was obtained from the straw mulch. Similarly, the mean percentage dry matter contents for crimson globe were 21.2, 22.3 and 15.5% for the control, straw mulch and compost mulch respectively. Straw mulch significantly increased dry matter content at 5% level of significance in comparison to the control and compost mulch. However, the control treatment had higher dry matter content compared to compost mulch. Globe dark red had the average dry matter contents of 36.5, 22.7 and 16.4% for the control, straw mulch and compost mulch respectively. Unlike in Detroit dark red and Crimson globe varieties, Globe dark red had a significantly higher dry matter in the control treatment in comparison to straw and compost mulches, with the least dry matter content found in compost mulch. The control treatment slightly improved dry matter content in comparison to the mulch treatments. On the other hand, variety had no significant impact on the mean dry matter contents. However, Globe dark red outperformed Detroit dark red and Crimson globe in terms of dry matter content.

4.1.8 Marketable and non-marketable yield.

Mulching improved the marketable yield while decreasing the non-marketable yield. There was a significant increase at 5% level of significance in the total marketable yield for all the three beetroot cultivars due to mulching. Detroit dark red had a total marketable yield of 539, 1452 and 1932g for the control, straw mulch and compost mulch respectively. Compost mulch had significantly higher total marketable yield in comparison to straw mulch. Similarly, Crimson globe had a total marketable yield of 443, 1121 and 2026g for the control, straw mulch and compost mulch respectively. Additionally, compost mulch had significantly higher total marketable yield in comparison to straw mulch. Globe dark red had a total marketable of 506, 1176 and 2423g for the control, straw mulch and compost mulch respectively. Overall, compost mulch produced superior yield in all three varieties, with Crimson globe control plot giving the lowest yield while the highest yield was produced by Globe dark red under compost mulch. However, there were no significant differences observed among the varieties. The final yields of all three cultivars provide a compelling result of improved returns and profits for farmers.

On the other hand, non-marketable beet yield was significantly reduced by the application of mulch. Detroit dark red cultivar had the average non-marketable yield of 169.3, 54.3 and 47.7g for the control, straw mulch and compost mulch respectively. The highest non-marketable yield was obtained from the control plot. Compost mulch had the least non-marketable beet yield. Crimson globe had significantly lower non-marketable yield in mulched treatments. The total non-marketable yields were 196, 48.3 and 43.3g for the control, straw mulch and compost mulch respectively. The highest non-marketable yield was also found in the control. Compost mulch outperformed straw mulch as significantly lower non-marketable yield was obtained from compost mulch. Similarly, Globe dark red, which had the minimum non-marketable yield under the compost mulch, had its non-marketable yield significantly reduced by the application of mulch. The total non-marketable yields were 193.3, 58.3 and 40.7g for the control, straw mulch and compost mulch respectively. The control had the maximum non-marketable yield. Overall, compost mulch was superior over straw mulch at reducing the total non-marketable yield. However, there were no significant differences observed among the varieties.

4.1.9 Net profit

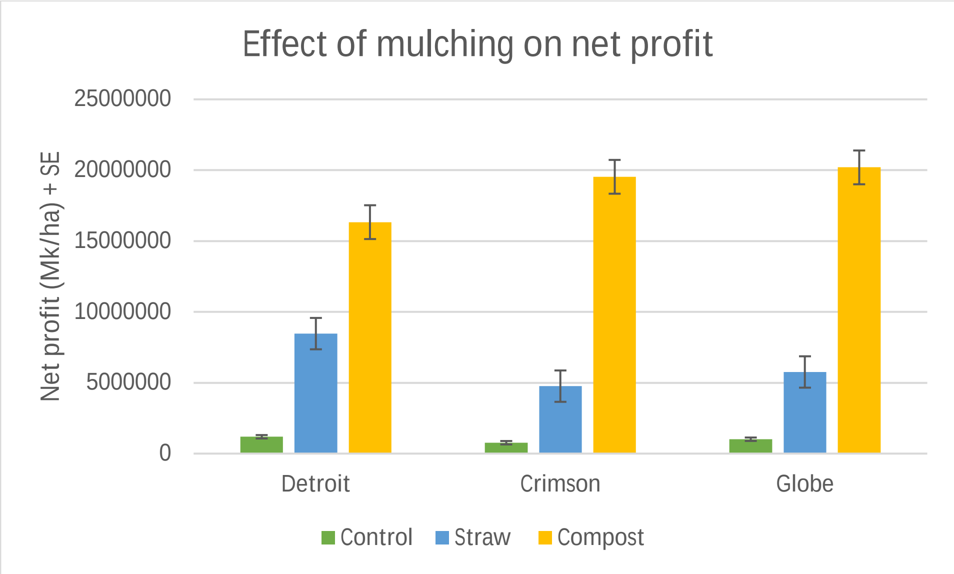

Figure 21: Effect of mulching on the net profit of beetroot per hectare

Figure 21: Effect of mulching on the net profit of beetroot per hectare 21 indicates the effect of mulching on the net profit for the three beetroot varieties per hectare. The net profit per hectare of each beetroot variety was greatly affected by the application of mulch. Compost mulch significantly improved the net profit at 5% level of significance in all the varieties. Detroit dark red had the least net profit in its control which had the mean net profit of Mk1, 186,667.00 and was followed by straw mulch which had the mean net profit of Mk8, 466,667.00. Compost mulch, which produced the highest net profit in this variety had the mean net profit of Mk16, 333,333.00 and was significantly higher than that of straw mulch. Similarly, mulching significantly increased the mean net profit in Crimson globe variety. The mean net profit for the control was Mk766, 667.00 per

hectare, significantly lower than the mean net profit for both straw and compost mulches. Straw mulch produced a mean net profit of Mk4, 760,000.00 per hectare while compost mulch, which produced a highly significant profit in this variety, had a mean net profit of Mk19, 533,333.00. Globe dark red had a mean net profit of Mk1, 013,333.00 for its control and it was significantly lower than the mean net profits for both straw and compost mulches. Straw mulch produced a net profit of Mk3, 760,000.00 per hectare while compost mulch had the highest net profit of Mk20, 200,000.00.

Table 3: Total cost of production and net profit of beetroot cultivation as influenced by mulching and variety.

Treatment (Mulch X Variety)	Cost of production in millions of Kwacha (Mk)	Marketable yield (t/ha)	Gross return in millions of Kwacha per hectare (Mk/ha)	Net return in millions of Kwacha per hectare (Mk/ha)
M_0 x V_1	4.21	10.8	5.4	1.2
M_0 x V_2	4.02	8.9	4.8	0.8
M_0 x V_3	4.04	10.1	5.0	1.0
M_1 x V_1	7.08	29	15.6	8.5
M_1 x V_2	7.74	25	12.5	4.8
M_1 x V_3	7.74	23	11.5	3.8
M_2 x V_1	9.67	38	26.0	16.3
M_2 x V_2	9.27	40	28.8	19.5
M_2 x V_3	9.80	46	30.0	20.2

Beetroot price used was the current market price for the product during the time the crop was harvested, Mk 500/kg.

M_0 = No mulch (Control), M_1 = Straw mulch, M_2 = Compost mulch, V_1 = Detroit dark red, V_2 = Crimson globe, V_3 = Globe dark red.

Overall, compost mulch improved the mean net profit for all the three varieties a great deal more than straw mulch. The control had the lowest net profit in all three varieties. The highest net profit in Globe dark red variety. However, no significant differences were observed among the varieties. The clear gains in net profit across all three varieties under both mulch regimes is a valuable statement for farmers who are looking at how to optimize their systems, especially if they are new to growing beetroot. The outcomes are not a real surprise, except that the extent of the gain from using mulch is considerably higher than anticipated. All of this is in concurrence with several previous studies on mulch in vegetable systems.

CHAPTER 5
Discussion

5.1 Introduction

This discussion is in two parts and limited to comparing the results to other studies on crops similar to beetroot if beetroot is not previously the subject of publication. In general, the results show a strongly positive result in the application of mulch to beetroot crops in the Malawi trials.

5.1.1 Crop physiology

The published work on vegetable crops all concur with the positive impact of mulch on plant height, especially in short season crops. No published work focused on beetroot growth so comparisons can only be made with other crops. Awodoyin et al. (2010) found that mulching increased plant height in tomato plants, which agrees with the current study. Tesfa, Asres, and Woreta (2018) found that mulching significantly increased plant height in lettuce. Similarly, Woldetsadik et al. (2003) found that mulch application increased plant height in shallots. Kayum et al. (2008) reported that mulching significantly increased height ginger plants. These results are in accordance with other studies which worked with capsicum Paul et al. (2013), okra Adekiya et al. (2017) and sesame (Teame et al., 2017). Grass mulch treatment produced relatively higher plant height in radish in comparison to control Carmichael et al. (2012) which is in accordance with the current study. Mahmood et al. (2002) also reported of improved plant height in mulched potatoes due to reduced soil temperature. The increase in plant height in these vegetables was attributed to increased soil moisture and optimal temperatures in mulched plots, which promoted growth.

Wang et al. (2009) found that mulching reduced soil temperature, which provided optimum temperature for potatoes which in turn improved plant height in two experiments. Similarly, Al-Zohiri and Samy (2013) found that mulching improved plant height in potatoes. Additionally, Cauliflower plants had their height significantly improved due to mulch application (Singh & Singh, 2019). These results were attributed to the improvement in the microclimate of mulched plots, which in turn provided suitable conditions for plant growth. Goel, Shankar, and Sharma (2020) found that mulching increased plant height in potatoes which was the case in the current study. Jaysawal

(2018) found that both organic and inorganic mulches increased plant height in carrots. Barakat et al. (2020) reported that different mulches increased plant height in potatoes due to improved water efficiency in mulched plots, which agrees with Biswas (2018) who also had similar observations in carrots.

This study further found that mulching improved the number of leaves in beetroot which is in accordance with several broader studies. Acharyya et al. (2020) found a similar trend in sugar beet plants grown under mulch. Carrots grown under mulch had significantly higher leaf numbers (Hasan et al., 2018). Similarly, Kushwah et al. (2013) found that mulching increased leaf number in ginger plants. Al-Zohiri and Samy (2013) found that mulching significantly improved leaf number in potatoes and attributed the results to improved microclimate in mulched plots. Similarly, carrots grown in mulched plots had significantly more leaf numbers (Biswas, 2018; Jaysawal, 2018).

Paul et al. (2013) stated that water use efficiency in mulched plots might be the cause for increased leaf number in capsicum plants. Sharma and Sharma (2003) stated that mulching improved soil moisture in plants, which in turn improved growth and produced more leaves. Manyatsi and Simelane (2017) found that organic mulches significantly increased the number of leaves in spinach, which agrees with Tesfa et al. (2018) who reported of increased number of leaves in lettuce plants grown under mulch. Contrary to these results, Lee and Park (2020) found that mulching did not influence leaf numbers in radish plants and their results were attributed to the genetic makeup of plants.

Kayum et al. (2008) found that mulching increased leaf length and width in tomato plants. These results agree with Sharma and Sharma (2003) who found that mulching produced a significant improvement in leaf size of strawberry plants, which agrees with the current study. The length of carrot leaves was improved by the application of different mulches (Jaysawal, 2018) . Lee and Park (2020) found that application of mulches significantly increased leaf length in radish. Manyatsi and Simelane (2017) found that spinach leaves had their length and width improved by the application of mulch. The increase in leaf length and width in these studies was attributed to improved soil microclimate in mulched plots which in turn improved plant growth and these findings are in accordance with the findings of the current study.

Several authors concur on the positive impact of mulches on vegetable crop leaf fresh and dry weights. The primary research to note is that of Maboko, Du Plooy, Sithole, and

Mbave (2018) found that mulching improved leaf dry weight in Swiss chard and attributed the findings to improved water use efficiency, which agrees with the current study. Swiss chard is also a crop of the Chenopodiaceae family and hence the closest related published outcome to this trial. Ruiz et al. (1999) found that mulching increased leaf dry weight in potatoes. Singh and Singh (2019) found that mulching increased leaf fresh weight in cauliflower. Dry weights of potato leaves were significantly improved by mulch application (Barakat et al., 2020). Jaysawal (2018) and Biswas (2018) found that mulching improved both fresh and dry weight of leaves in carrots. Similarly, Lee and Park (2020) found that mulching improved leaf fresh weight in radish plants which agrees with Shaw and James (2007) who found that mulching improved leaf fresh weight in sweet potatoes. Additionally, mulch application improved both the leaf fresh and dry weights in spinach (Manyatsi & Simelane, 2017).

Ruiz et al. (1999) found that mulching improved the dry weight of potato tubers and the results were attributed to improved nitrogen metabolism in mulched plots. Rani et al. (2016) found that water hyacinth mulch improved the fresh weight in storage roots of carrots due to improved water use efficiency. Jaysawal (2018) found that mulching improved the total root fresh and dry weights in carrots. Similarly, Biswas (2018) stated that improved root fresh weight in carrots grown under mulch was due to improved soil productivity, which agrees with the current study. Shaw and James (2007) found that the root fresh weight of sweet potatoes grown under mulch was significantly improved. Lee and Park (2020) found that mulching increased root fresh weight in radish which was attributed to improved heat accumulation in mulched plots which subsequently increased growth.

Rahman et al. (2018) reported significantly higher root diameter in carrots grown under different mulches and organic manure. However, the largest root diameter was found in plots which had a combination of mulch and organic manure. These results agree with the current study, which found that mulching consistently improved root diameter in beets. Bharati et al. (2020) found that mulching increased potato tuber diameter which is also in accordance with this study. Contrary to the results of this study, Olfati et al. (2008) reported that organic mulches had no effect on root diameter in carrot roots. Barakat et al. (2020) found that mulch application improved root diameter of potato tubers in all grades of potatoes. Jaysawal (2018) reported that different mulches improved root diameter in carrots due to improved soil microclimate. Biswas (2018) found the greatest root diameter in mulched carrots. Similarly, Lee and Park (2020) found that mulching increased root diameter in radish, which confirms the findings of this study.

Franczuk, Jabłońska-Ceglarek, Zaniewicz-Bajkowska, Kosterna, and Rosa (2009) found that mulch application reduced dry matter content in red cabbage which agrees with the findings of the current study. These results are in accordance with several research works, which have reported a significant reduction of dry matter contents in mulched vegetables. Contrary to the results of this study, Rahman et al. (2018) reported significantly higher dry matter content in mulched plots than control, this agrees with Solaiman et al. (2008) who reported significant increase in dry matter content in turnip roots grown under mulch. Ahmed et al. (2017) found that mulching improved dry matter content in potato tubers. Woldetsadik et al. (2003) found significantly higher dry matter in shallots grown under straw mulch and control compared to other mulch types. These results are in accordance with the current study which found no differences on dry matter content in straw mulch and control. In other studies, mulching significantly reduced dry matter content in carrots (Olfati et al., 2008). Some of the dry matter content results can be attributed to the consistent watering regime applied to the trials and the ability of the mulches to maintain water availability for the plants. The relationship of dry matter to quality of root crops has been studied in crops other than beetroot. Li et al. (2021) found that mulching increased quality in potatoes. Similarly, Moursy et al. (2015) found that mulching improved sugar beet quality. Hou et al. (2019) found that mulching improved dry matter content in sweet potatoes of different cultivars.

5.1.2 Economics of beetroot production

These results aligned to the marketable yield agree with Al-Zohiri and Samy (2013) and Lehar et al. (2017) who reported that mulching increased marketable yield in potatoes. Goel et al. (2020) reported improved potato tuber yield in plots covered with wheat, rice and pine mulches. The increase in beetroot yield in this study is in agreement with Malik et al. (2018) who reported that mulching significantly increased yield in sugar beet by over 12% in comparison to the control. Similarly, Artyszak et al. (2014) reported improved yield in sugar beet roots due to the application of mulch. This is also in accordance with Yordanova and Gerasimova (2016) who found that mulching increased the yield in beetroot seven times more than the control. Similarly, Genger et al. (2018) showed that mulching improved potato yield, due to reduced weed infestation in mulched plots which is in accordance with the current study. Hasan et al. (2018) reported yield improvement in carrots grown under organic mulch.

It has also been reported that mulching increased rhizome yield in ginger plants Kushwah et al. (2013). Vavrina and Roka (2000) reported improved marketable yield in onions grown under mulch. Carvalho, Ribeiro, et al. (2018) reported a similar trend in marketable yield of onions grown under organic mulch. They attributed the results to the supply of nutrients of organic mulches through decomposition of organic mulches thereby increasing yield. Similarly, the results of the current study agree with Solaiman et al. (2008) who found that turnip plants grown under mulch had significantly higher root yield in comparison to the control. These results confirm what was earlier reported, that mulching assisted in moisture conservation hence increasing the size of root vegetables and preventing defects such as toughness, strong flavour, cracking and misshapen roots, thereby increasing total marketable yield (Carmichael et al., 2012).

Momirovic et al. (1996) attributed the increase in potato yield to the effect of mulching on soil temperature, as it was observed that mulched plots had significantly higher soil moisture and lower root zone temperature compared to the control plot. Ruiz et al. (1999) stated that mulches promote high utilization efficiency of nitrogen due to optimum root zone temperature, which in turn resulted in higher tuber yield. Miyasaka, Hollyer, and Cox (2001) found that mulch application significantly improved taro yield compared to the control in an experiment which was conducted in a period of two years. The second year was drier and had the greatest taro yield and quality due reduced soil moisture loss and in-creased plant water uptake in mulched plots. Similarly, Kar and Kumar (2007) reported of improved yield in potato tubers grown under mulch. The results were attributed to improved water use efficiency and reduced soil temperature in mulched plots. These findings are also supported by Allah, Omar, Eid, and Elsaady (2009) who reported significantly higher tuber yield in mulched potatoes.

Inusah, Wiredu, Yirzagla, Mawunya, and Haruna (2013) reported of improved yield in onions which were grown under mulch. Similarly, Baba, Wiredu, Yirzagla, Mawunya, and Haruna (2013) found that organic mulches significantly improved yield In dry land grown onions due to improved water efficiency. Biswas (2018) found that mulches significantly reduced non-marketable yield in carrots. Similarly, Šlosár et al. (2016) found that mulches significantly reduced non-marketable yield in sweet potatoes, which confirms the results of this study. Laurie, Maja, and Du Plooy (2015) found that plastic and newspaper mulch reduced non marketable yield of sweetpotatoes as they effectively controlled weeds compared to bare plots which in turn reduced the cost of hand weeding and resulted in improved profits.

Tesfa et al. (2018) reported of higher net returns in carrots grown under hyacinth mulch. Vavrina and Roka (2000) worked with sweet onions and reported of increased net profit in mulched crop. Adekiya et al. (2017) okra, Thwe (2020) chili, and Kumar (2015b) for maize. Jalota et al. (2007) stated that mulching conserved soil moisture compared to bare soils, which reduced irrigation frequency and increased yield, hence increasing profit. Mulching improved marketable yield in carrots which subsequently improved the net economic return and the findings were attributed to less weed infestation in mulched plots which resulted in less herbicide usage (Ojowi, Ariga, Michieka, & Kimenju, 2013). M. Singh (2018) reported of higher gross and net return in a potato crop that was grown under rice husk mulch compared to the control. These findings agree with the findings of this study and are also supported by Lin et al. (2012) who reported the highest net return in mulched potatoes. Similarly, Inusah et al. (2013) found that mulching improved the average net return in onion crop.

CHAPTER 6

Conclusion and Recommendations

6.1 Conclusion

In conclusion, the results of this study have shown that mulching with compost and straw had a wholly positive influence on all growth, yield and profit parameters in all three beetroot varieties. The application of mulch did not influence dry matter content in beets as there were no differences with the control. However, compost mulch had the least dry matter value. Plant height, number of leaves, leaf length and width, leaf fresh and dry weights, root fresh and dry weights, root diameter, marketable yield, and net profit were highly improved by the application of organic mulches. Overall, compost mulch was found to be more economical than straw mulch as it greatly improved yield parameters, which resulted in higher economical returns. On the other hand, the three beetroot varieties had similar response to mulch application, no significant differences were observed among them. Detroit dark red outperformed other varieties in growth with the highest plant height in all the treatments. However Globe dark red was superior to the other varieties as it produced the maximum marketable yield. This variety was particularly suited to the environment of the trial and therefore worth promoting to farmers in Malawi. Therefore, based on the findings of this study, it can be concluded that mulching is the best practice as it can improve water use efficiency in beetroot production thereby improving yield and quality, which in turn improves profit among smallholder farmers. Finally, it was noted that mulching had a similar effect on different beetroot varieties, which will enable different farmers to benefit from the use of mulches.

6.2 Recommendations

Based on the findings of this study, conducted to evaluate the impact of organic mulches on growth, yield and quality of beetroot, it is recommended that:

1. The study could help vegetable farmers, especially small- scale growers, facing challenges with irrigation water, since mulching has proven to improve yields due to its efficiency in saving water and irrigation time.
2. Farmers should be encouraged to adopt compost mulch as it proved to be superior to straw mulch.

3. Further studies should be done to evaluate the response of beetroot to mulching in different seasons.
4. Other crop residues should be evaluated to assess their impact on conserving soil moisture and their effect on beetroot yield, growth, quality and profitability.
5. More varieties should be tested to assess their performance in tropical conditions.

6.3 Limitations

1. This project was initiated right before the Covid-19 Lockdown period (March 2020) which affected all economies globally and meant the researcher was unable to return to the university in NZ for post-trial work, effectively having to complete the project remotely with supervision and advice mostly received via regular online meetings.
2. The study was conducted at one site and may not be a true reflection of the response of beetroot to mulch application as beetroot is grown in different places, which experience different weather patterns during the growing season. Therefore, the recommendation of this study is only applicable to farmers surrounding the study site.
3. The experimental plot was small, and this may not provide a clear picture of the effect of mulches on response of beetroot to mulching.
4. Resources were insufficient, this limited the use of more organic mulches to two types only for this experiment.

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APPENDICES

Appendix I: Production costs and market price for beetroot

Treatment	Cost of production	Marketable yield (t/ha)	Cost of beetroot/kg (MK)	Gross return (Mk/ha)	Net return (Mk/ha)
M_0DDR	4,213,333.00	10.8	500	5,400,000.00	1,186,667.00
M_0CG	4,033,333.00	8.9	500	4,800,000.00	766,667.00
M_0GDR	4,036,667.00	10.1	500	5,050,000.00	1,013,333.00
M_1DDR	7,083,333.00	29	500	15,550,000.00	8,466,667.00
M_1CG	7,740,000.00	25	500	12,500,000.00	4,760,000.00
M_1GDR	7,740,000.00	23	500	11,500,000.00	3,760,000.00
M_2DDR	9,666,667.00	38	500	26,000,000.00	16,333,333.00
M_2CG	9,266,667.00	40	500	28,800,000.00	19,533,333.00
M_2GDR	9,800,000.00	46	500	30,000,000.00	20,200,000.00

Price for beetroot per kg was Mk500.
Gross return = Total marketable yield * Price for beetroot per kg
Net return = Gross return - total production cost.

Appendix II: ANOVA tables and graphs

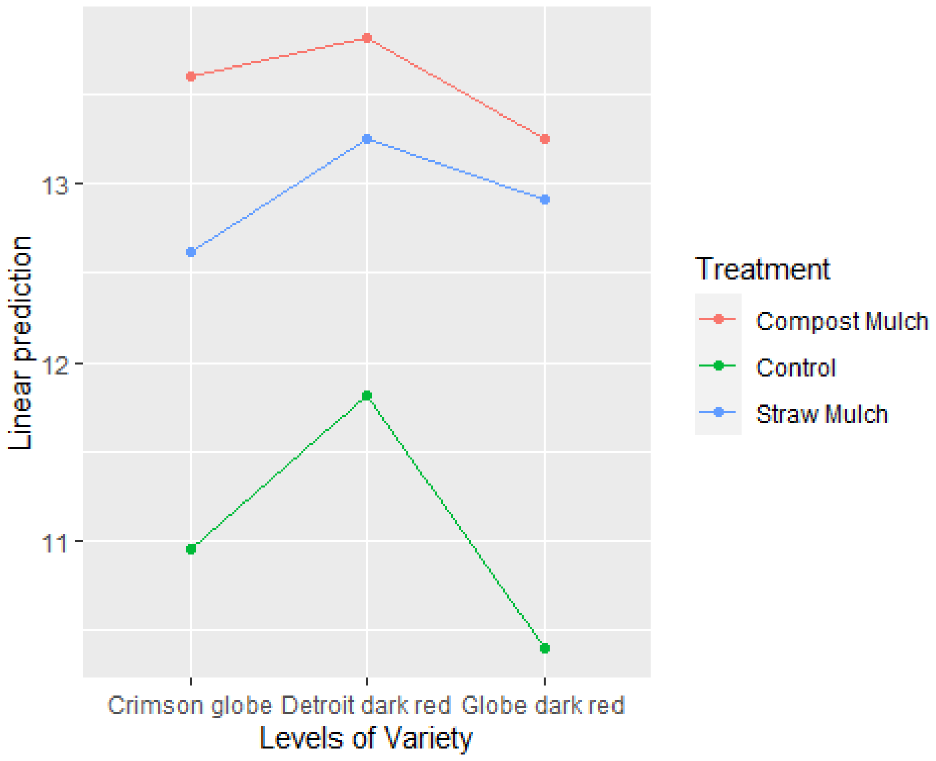
Plant height

Analysis of Variance Table

Response: Plant height

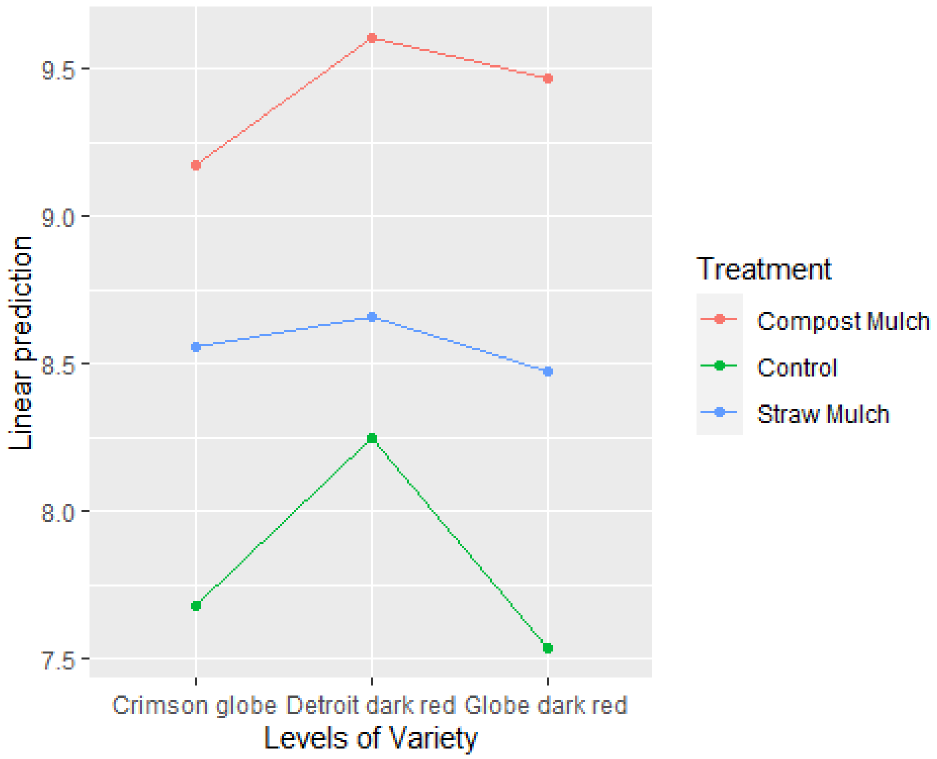
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Days	6	9784.8	1630.80	799.4550	< 2.2e-16	***
Treatment	2	1707.4	853.68	418.4913	< 2.2e-16	***
Variety	2	162.6	81.28	39.8436	< 2.2e-16	***
days: Treatment	12	1715.7	142.98	70.0902	< 2.2e-16	***
Days: Variety	12	13.6	1.13	0.5538	0.8796	
Treatment: Variety	4	69.2	17.29	8.4764	9.267e-07	***
Days:Treatment:Variety	24	31.2	1.30	0.6375	0.9106	
Residuals	1449	2955.8	2.04			

*Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*



Number of leaves

```
Analysis of Variance Table

Response: number of leaves
                        Df Sum Sq Mean Sq  F value    Pr(>F)
days                     7 8533.5 1219.07 1280.6160 < 2.2e-16 *
**
Treatment                2  734.2  367.10  385.6339 < 2.2e-16 *
**
Variety                  2   48.8   24.41   25.6372 1.083e-11 *
**
days: Treatment         14  577.0   41.22   43.2971 < 2.2e-16 *
**
days: Variety           14    2.8    0.20    0.2088    0.9992
Treatment: Variety       4   27.4    6.84    7.1844 9.838e-06 *
**
days:Treatment:Variety  28   10.8    0.38    0.4042    0.9977
Residuals                        1656  1576.4           0.95


Signif. Codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```



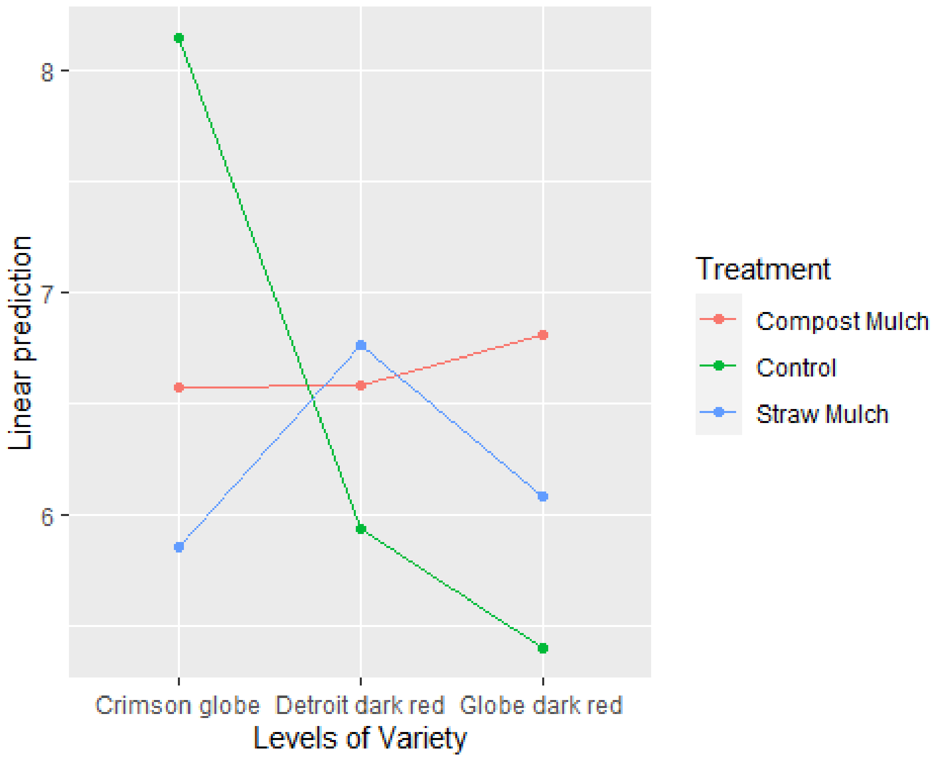
Leaf size

Analysis of Variance Table

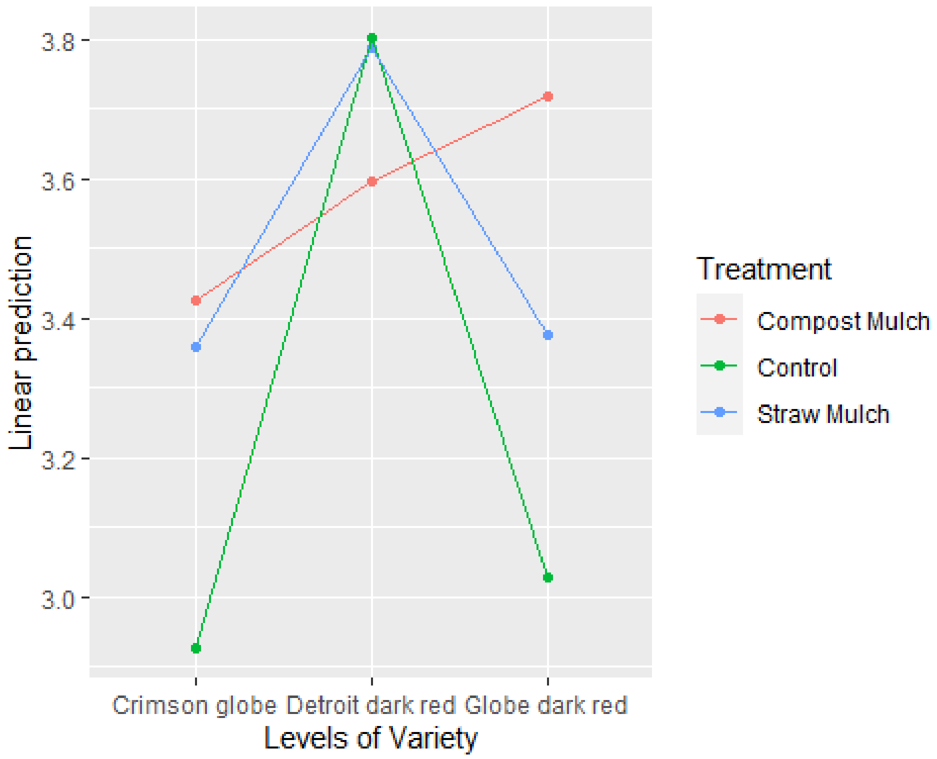
Response: Leaf length

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
days	4	195.4	48.844	2.9946	0.01896	*
Treatment	2	10.9	5.460	0.3348	0.71577	
Variety	2	34.9	17.471	1.0711	0.34387	
days: Treatment	8	124.6	15.579	0.9551	0.47132	
days: Variety	8	96.5	12.060	0.7394	0.65667	
Treatment: Variety	4	154.2	38.555	2.3637	0.05303	.
days:Treatment:Variety	16	197.8	12.365	0.7581	0.73263	
Residuals	315	5138.0	16.311			

Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

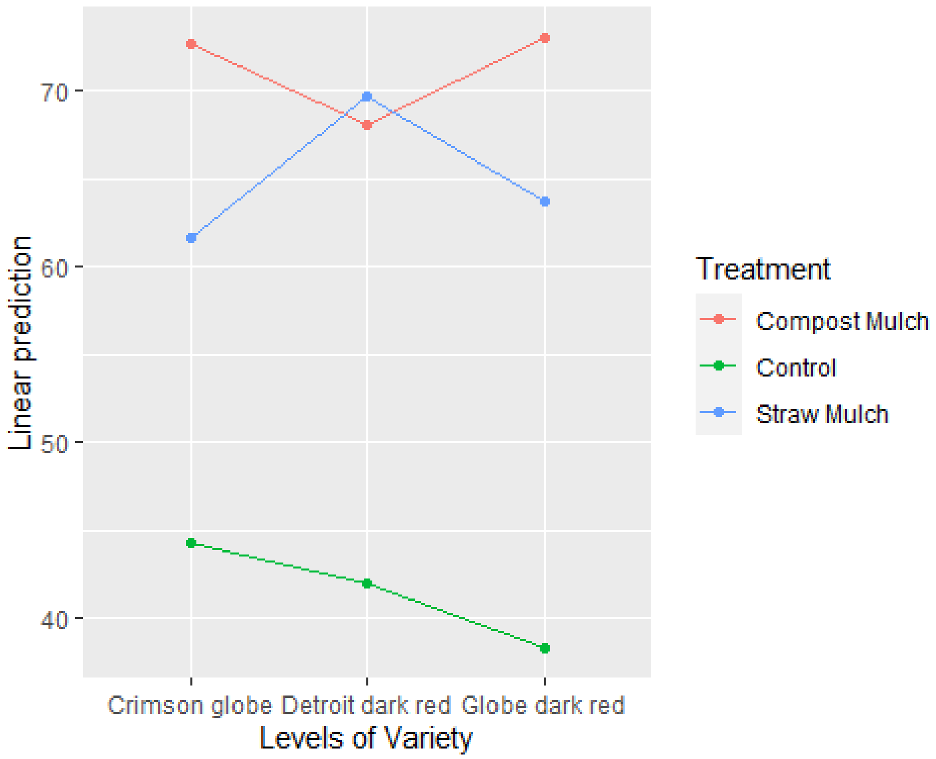



```
Analysis of Variance Table

Response:                    Leaf                      width
                        Df   Sum Sq Mean Sq  F value     Pr(>F)
days                     4 104.244 26.0610 108.0267 < 2.2e-16 **
*
Treatment                2   7.102  3.5508  14.7184 7.748e-07 **
*
Variety                  2  15.500  7.7498  32.1238 2.012e-13 **
*
days: Treatment           8  10.057  1.2571   5.2110 3.937e-06 *
**
days: Variety              8   0.347  0.0433   0.1796     0.9936
Treatment: Variety        4   9.292  2.3230   9.6292 2.336e-07 *
**
days:Treatment:Variety  16   0.623  0.0389   0.1613     0.9999
Residuals                             315     75.992     0.2412

Signif. Codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```



Leaf fresh and dry weights

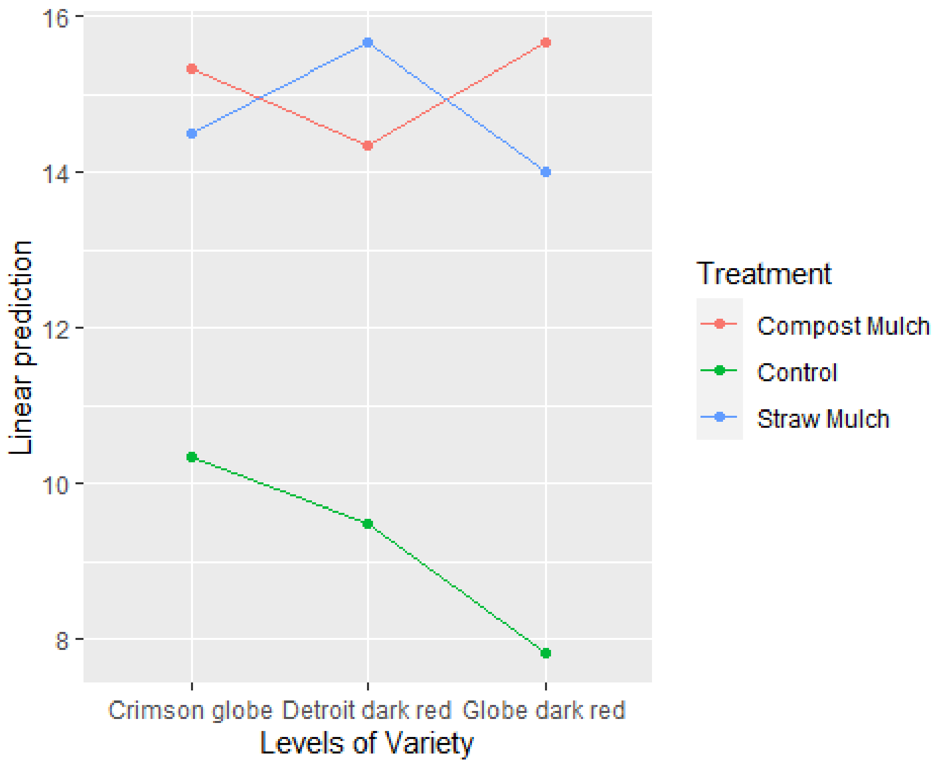
```
Analysis of Variance Table

Response: leaf fresh wt g

                    Df Sum Sq Mean Sq F value    Pr (>F)
Treatment            2 4405.4 2202.70 86.9488 5.621e-10 ***
Variety              2   12.1    6.04 0.2383    0.7904
Treatment: Variety 4 193.7    48.43 1.9115    0.1522
Residuals           18 456.0    25.33

Signif. Codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```



Analysis of Variance Table
Response: Leaf dry wt_g

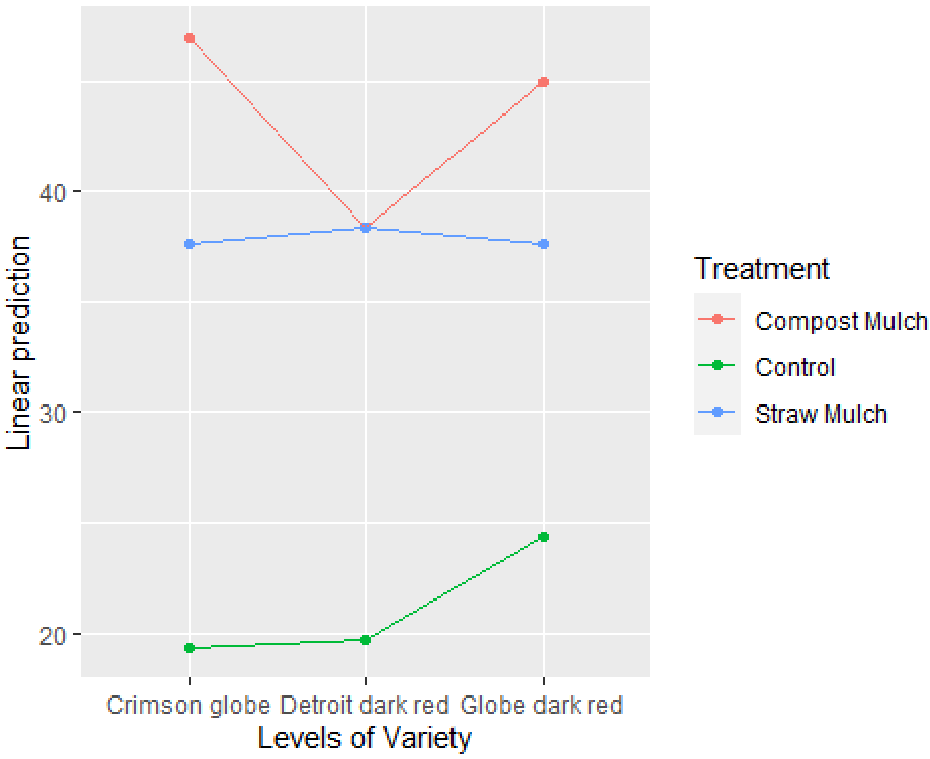
	Df	Sum Sq	Mean Sq	F value	Pr (>F)	
Treatment	2	195.241	97.620	55.7831	1.928e-08	***
Variety	2	3.852	1.926	1.1005	0.3541	
Treatment: Variety	4	13.148	3.287	1.8783	0.1581	
Residuals	18	31.500	1.750			

Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1



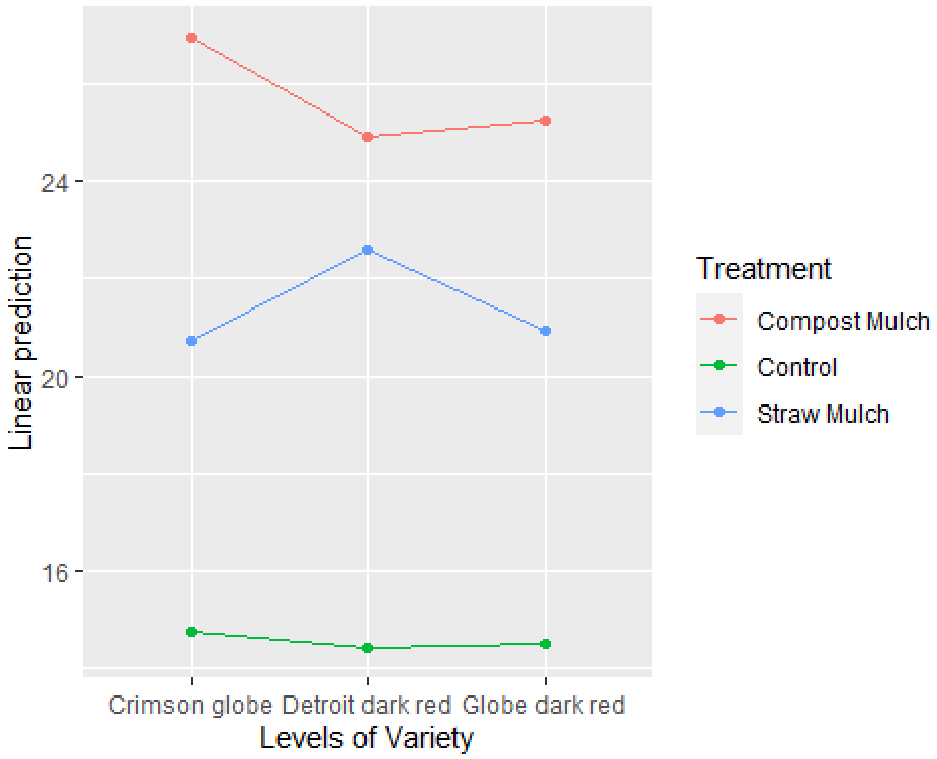
Root fresh and dry weight

```
Analysis of Variance Table

Response: Root dry wt_g
                    Df  Sum Sq  Mean Sq  F value    Pr (>F)
Treatment            2 2433.41 1216.70  59.0845 1.232e-08 ***
Variety              2   60.52   30.26   1.4694    0.2564
Treatment: Variety   4  110.81   27.70   1.3453    0.2917
Residuals           18  370.67   20.59

Signif. Codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```



Root diameter

```
Analysis                of                Variance                Table

Response:                         Root                          diameter
                  Df    Sum    Sq    Mean    Sq    F    value    Pr    (>F)
Treatment                2  1513.76  756.88  262.1633  <2e-16  ***
Variety                  2       4.28       2.14      0.7419  0.4803
Treatment:  Variety  4      32.44        8.11      2.8089  0.0328   *
Residuals           63 181.88     2.89


Signif. Codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

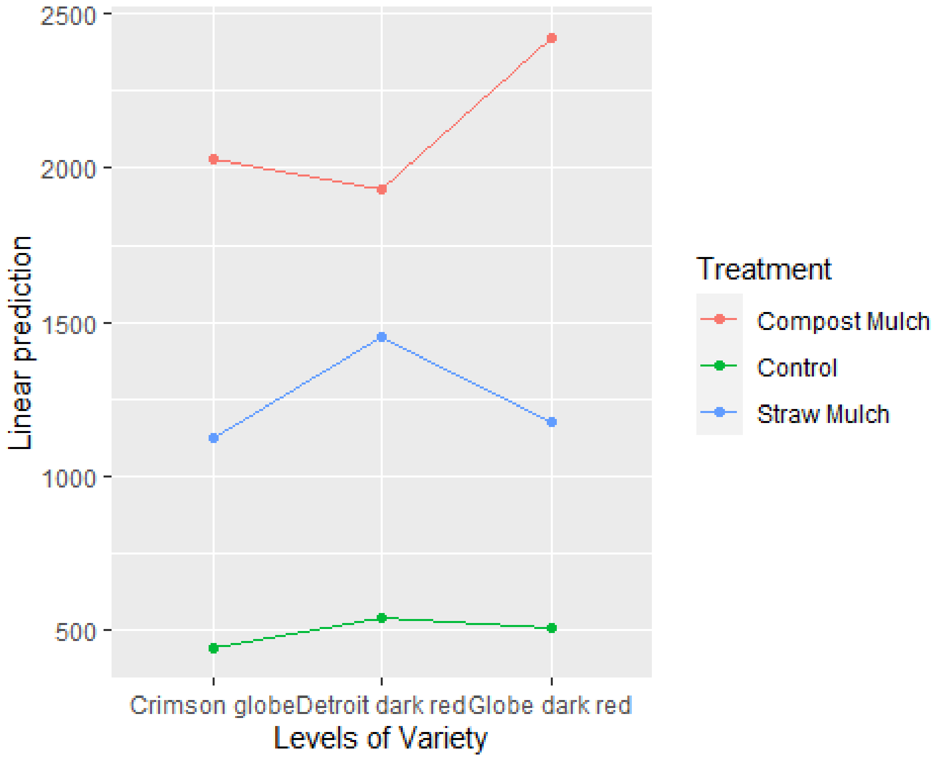


Marketable and non-marketable

Response: Marketable yield g

	Df	Sum Sq	Mean Sq	F value	Pr (>F)	
Treatment	2	11996845	5998422	60.0953	1.079e-08	***
Variety	2	135761	67880	0.6801	0.5191	
Treatment: Variety	4	474232	118558	1.1878	0.3497	
Residuals	18	1796672	99815			

Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

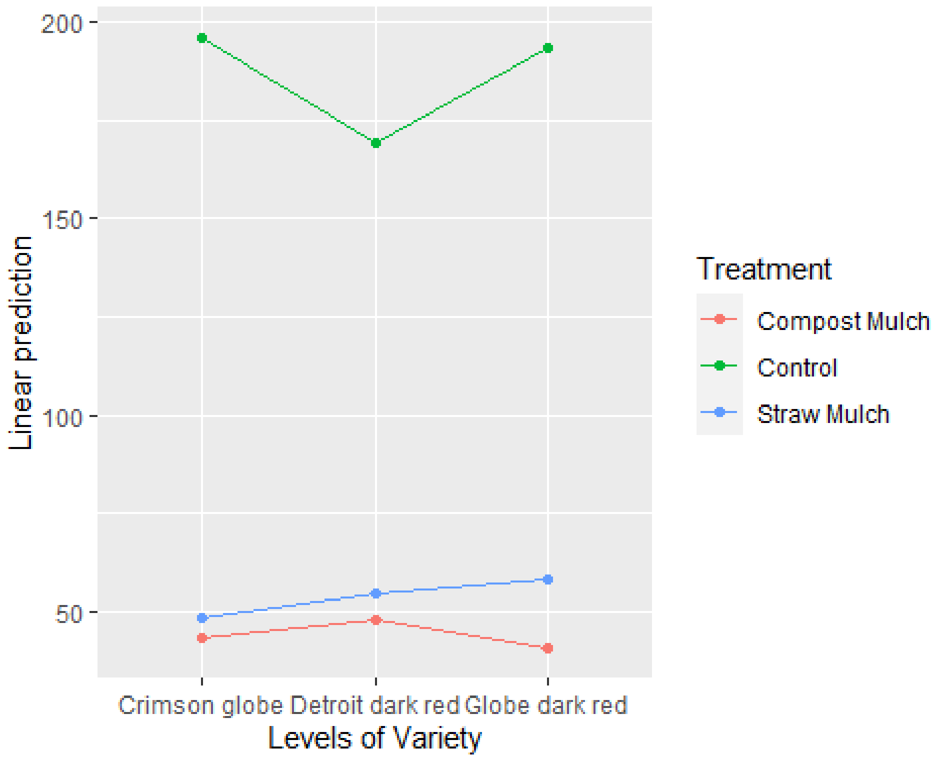


Analysis of Variance Table

Response: Non-mraketable yidle g

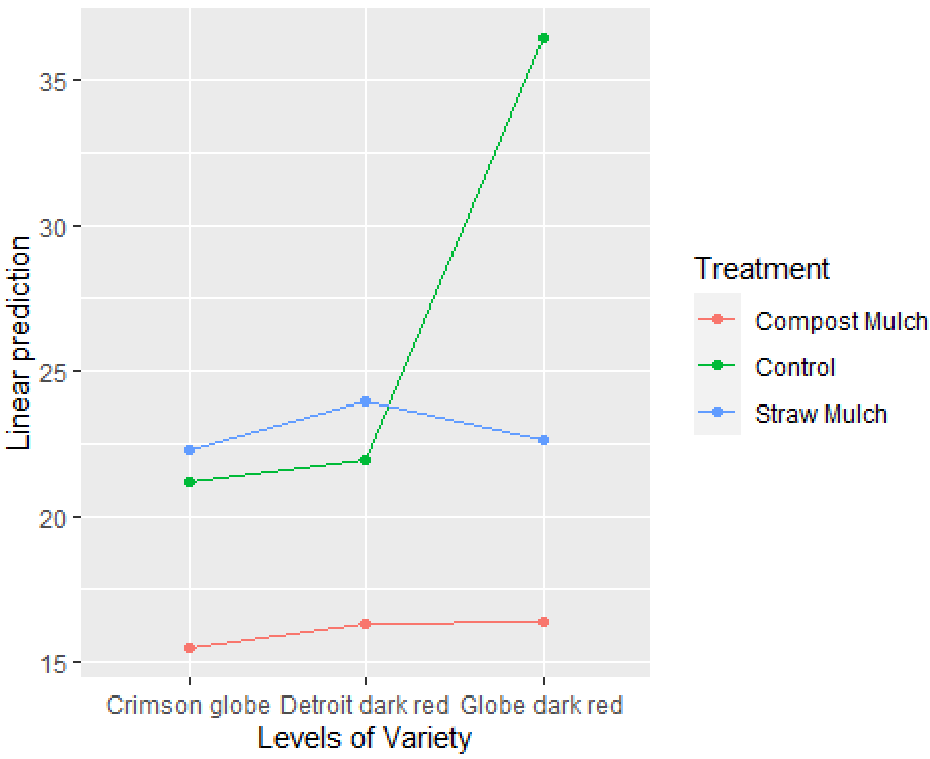
	Df	Sum Sq	Mean Sq	F value	Pr (>F)	
Treatment	2	113776	56888	25.1227	6.177e-06	***
Variety	2	243	122	0.0537	0.9479	
Treatment: Variety	4	1278	319	0.1411	0.9646	
Residuals	18	40759	2264			

Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1



Dry matter content

```
Analysis            of              Variance            Table

Response:              Dry              matter              co
                 Df      Sum    Sq   Mean   Sq   F   value     Pr(>F)
Treatment                2    508.20  254.100    3.5936  0.04862  *
Variety                    2    154.01    77.005    1.0891  0.35771
Treatment:  Variety      4     297.90     74.475     1.0533   0.40781
Residuals                                18     1272.75        70.708

Signif. Codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```


35
30
25
20
15
Linear prediction
Crimson globe
Detroit dark red
Globe dark red
Levels of Variety
Treatment
Compost Mulch
Control
Straw Mulch

Appendix III: Fertilizer calculations

$$\text{Fertilizer required (kg/ha)} = \frac{\text{Rate (kg/ha) x 100}}{\text{C (\%)}}$$

$$\text{Fertilizer required} = \frac{\text{150kg/ha x 100}}{\text{23(\%)}} = \text{652 kg of NPK per ha.}$$

To get the amount required on the experimental plot, the amount of fertilizer was divided by 10000m2 and then multiplied by the area of the plot.

Therefore, 2.22kg of fertilizer was applied which provided for all the required nutrient rates.