Interactive effects of weeding regimes and seed shapes on growth, yield and nutrient components of SC701 green mealies during summer and winter planting seasons under rain-fed condition

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DECLARATION

I, Akinnuoye Dolapo Bola, certify that the material reported in this thesis represents my original work, except where acknowledged. I further declare that these results have not otherwise been submitted in any form for any degree or diploma to any university.

Signature ________________

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I, Professor Albert Thembinkosi Modi supervised the above candidate in the conduct of her dissertation study.

Signature ______________________

Prof. A.T. Modi

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DEDICATION

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GENERAL ABSTRACT

Maize and weeds interfere with growth activities of each other to a varying degree. Weeds compete for water, mineral nutrients, and light and hinder harvest operations. Maize plants are susceptible to weed competition and yield losses are estimated at 30% to complete crop failure. Seed shape and size can also be an important factor to consider for improving maize yield because it influences seedling vigour. The aim of this study was to evaluate the interactive effect of seed shape and size of SC701 maize hybrid on seed quality. Thereafter, the effect of seed shape and weed competition on yield of SC701 was evaluated in field trials planted during summer and winter, in KwaZulu-Natal.

Germination test was carried out on SC701 differentiated on the basis of seed shape, (round and flat), and seed size (large and small). Seeds were germinated using four different temperature regimes: constant 20°C and 30°C as well as two alternating temperature regimes, 15/20°C and 20/30°C (12/12 hrs.). The experiment was laid out as a split-plot design with temperature being the main factor; variety was sub factor with four replications. Upon termination of the experiment, germination rate (GR), mean germination time (MGT), germination velocity index (GVI), vigour index (VI), seedling shoot and root lengths, seedling fresh and dry mass and seedling shoot: root ratio were determined. Field trials were used to evaluate the interactive effect of seed shape and weeding on SC701 harvested as green mealies during summer and winter seasons under rainfed conditions at Ukulinga and Umbumbulu in KwaZulu-Natal. At harvest, nutritional quality of the green mealies was determined.

Results of seed quality showed no significant differences in final germination and MGT among seed sizes and shapes at different temperature regimes. Highly significant differences ($P<0.001$) were observed for daily germination, GR, GVI and VI. Results of daily germination, GR, and GVI showed that flat seeds germinated faster than round seeds at constant temperatures while in terms of seed size, small seeds germinated faster than large seeds. A similar trend was observed for VI. Alternating temperatures (20/30°C) produced higher VI when compared with constant temperatures for all varieties.

Results from the field trials showed that emergence was faster during summer than during winter season. Flat seeds emerged better by 1.4% than round seeds. Maize plants were taller ($P<0.001$) in summer than in winter. Double weeding had the tallest ($P<0.05$) plants for both seasons. Double weeding had the highest leaf number followed by single weeding while no weeding had the lowest leaf number for both seasons. Weeding treatments had a significant ($P<0.05$) effect on days to tasseling (DTT) during both seasons and at both sites. Days to tasseling was faster by 29.1% during summer than winter while DTT in no weeding were 15.38% and 10.45% longer than DTT in double weeding during summer and winter respectively. Stomatal conductance (SC) and chlorophyll content index (CCI) were significantly higher ($P<0.001$) during the summer than winter season. Weeding frequencies had a significant ($P<0.05$) effect on harvest index, total biomass, ear prolificacy, kernel rows per cob, kernels per row and cob mass.

Weeding frequency was shown to have an effect on nutritional quality of green mealies as indicated by results of total soluble sugars, starch and protein content; they were low with decreasing weeding frequency. Proline accumulation was highest in the no weeding treatment indicating the crop was stressed.

It is concluded that although, standard germination test values showed that flat small seeds germinated faster at constant than alternating temperatures, this did not translate to better field emergence. In the field, seed shape of SC701 had no influence on improving crop vigour and ability to compete with weeds. Furthermore, the present study showed that season plays an important role in growth and development of green mealies in that winter planting of maize resulted in low yield production. Further research on the effect of weed competition on growth, yield and nutritional value of SC701 conducted under irrigated conditions during winter planting season for green mealies production is therefore recommended.

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CHAPTER ONE

LITERATURE REVIEW

1.1 Introduction

In Southern Africa, maize is the dominant field crop and source of dietary carbohydrates for human and animal consumption (Gouse et al., 2006, FAOSTAT, 2012). In South Africa, maize is the most important staple food, accounting for over 50% of calories in local diets (McCann, 2005). Being a staple food, it plays an important role in the economy of South Africa and is produced throughout the country under diverse environmental conditions (du Plessis, 2003). The major producing provinces are North West, Free State and Mpumalanga. In KwaZulu-Natal, maize production accounts for only 4.6% of total maize production in South Africa (Walker and Schulze, 2006) and more than 75% of harvested maize is for household consumption. However, it forms part of the agricultural activities that provide 60% of the rural population in the province with food security and a sole or complementary income (Walker and Schulze, 2006).

White maize is preferred for human consumption and is also used for animal feed and for some processed foodstuffs such as cereals. It is also used to produce starches and syrups used in a vast array of foods and industrial products. Maize can be harvested when fresh (dough stage) which is referred to as green mealies or when dry which is referred to as dry grain. Green mealies are highly valued and one of the most important crops in Southern Africa and highly perishable compared to dry grain because of their high water content (Department of Agriculture, 2003, van Averbeke, 2008). Green mealies are consumed mostly by South African and provide 35% of the nation’s carbohydrates, 15% of fat, and 31% of protein requirements in local diets (Shava et al., 2009). They are usually consumed boiled or as grains from roasted cobs and sometimes the grains are grounded to make mealie-bread (Shava et al., 2009). Green mealies are more nutritious than processed maize products such as maize meal because the milling process removes most of the germ and fibre (Hall et al., 1992). SC701 variety is among the recommended varieties for green maize production (van Averbeke, 2008).

Agronomic research on maize has largely focused on maximising grain production. Research focussing mainly at optimising green mealies production is lacking (van Averbeke, 2008). The low yields in green mealies production have been largely attributed to poor agronomic practices, with low fertiliser and plant population levels being among the most important factors limiting maize productivity (Fanadzo, 2007).

However even with its importance, maize especially green mealies production in South Africa still faces numerous challenges, for example, poor soil fertility and lack of resources to correct the soil nutrient deficiencies, inadequate and untimely weed control and inconsistent and inadequate rainfall (Jonga, 1998, Fanadzo, 2007). This has led to grain yields obtained by most maize farmers being below potential with an average of less than 3 t ha^{-1} being common (Fanadzo, 2007, Machethe et al., 2004). While rainfall still remains the most important limiting factor for increasing maize yield in South Africa (Machethe et al., 2004), weed management, cultivar selection and duration of the growing period are also factors that consistently affect yield in maize (Kgasago, 2006). Furthermore, due to the perceived adverse effects of climate change on maize production, efforts have been concentrated on developing high yielding varieties of maize. In the quest of developing these high yields varieties, considerable attention has been given to increasing various inputs, including seeding rates and fertilizers (Fanadzo et al., 2009), narrowing row spacing (Matsuoka et al., 2002), and making preventative applications of foliar fungicides (Jonga, 1998), growth regulators and biological stimulants (Mnkeni, 2007). This has led to increasing rates of yield improvement across South Africa. These higher rates are attributed to several factors including but not limited to genetic technologies that allow for greater expression of maize genetic yield potential by withstanding various crop stresses.

However, other agronomic practices such as weeding, critical periods for weeding, planting date selection and its effect on maize yields have not been fully explored for rain-fed agriculture by researchers in Africa, including South Africa. This is evident in the apparent lack of information on the response of drought sensitive maize and weed competition in the literature. Moreover, it is not yet known if green mealies from high yielding maize hybrids could be grown both in summer and winter season within a year in such warm climatic region like Kwazulu-Natal. Knowledge of this will not only increase the yield of maize within the province, but possibly also improve the financial capabilities of small-scale farmers. Generally, when a farmer plants green mealies in October-November planting season, harvest will coincide with a glut in the market and hence lower prices for the farmer. However, late cropping (March-April planting season) and possible harvest during winter when green mealies are in low supply will likely result in higher prices for the farmers' green mealies.

In this study it was hypothesised that green mealies can be planted in summer and winter within KwaZulu-Natal province. Therefore, the aim of the study was to evaluate the performance round and flat seeds of different sizes in terms of seed quality and with respect to production of the crop in a year. The crop was produced as green mealies using the popular SC701 hybrid that is marketed as “Flat” and “Round” seeds. In addition, weed competition with regards to weeding frequency was to evaluated.

1.2 Specific Objectives

- To compare the effect of seed size and shape on germination characteristics of SC701 maize hybrid under different temperature regimes.
- To compare the growth parameters and yield components of maize hybrid SC701 planted at two different planting seasons within a year atUmbumbulu and Ukulinga sites within KwaZulu-Natal.
- To compare the interactive effect of shapes and weeding regimes on the nutrient quality of SC701 maize green mealies.

1.3 Botany

Maize (*Zea mays, L.)* belongs to the family Poaceae (*Gramineae)* and the tribe Maydeae (Sikandar et al., 2007). Mexico is now widely accepted as the origin of maize (Sikandar et al., 2007). Maize is descended from the wild grass, teosinte (*Zea parviglumis*) which is still found in Mexico today (Matsuoka et al., 2002). Other grasses in this family include wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), rye (*Secale cereale*), sugarcane (*Sacharum officinarum*), sorghum (*Sorghum bicolor*) and rice (*Oryza sativa*) (Keller et al., 2012). One main difference between maize and other cereals is that it bears seed heads, ears, that are larger than any other grass. It is called corn or Indian corn in the United States. Maize is the first commonly grown crop in terms of production and area cultivated (FAOSTAT, 2012) and can be grown under different environmental conditions. Maize is used for human consumption and as a source of industrial products like animal feed, starch, oil and popcorn. It is also high in carbohydrates but low in protein, especially the vital amino acids (lysine and tryptophan) (Karimmojeni et al., 2010). It is also rich in dietary fibre and calories which are a good source of energy. Also, maize has a higher yield of food per unit than any other grain. This productivity is one of the main contributing factors of maize appeal to farmers.

Maize is a tall, determinate annual C4 plant varying in height from 0.3 to 7 meters producing large, narrow, opposing leaves (about a tenth as wide as they are long), borne alternately along the length of a solid stem (McCann, 2005). The stem generally attains a thickness of three to four centimeters. The inter nodes are short and fairly thick at the base of the plant; they become longer and thicker higher up the stem, and then taper again. The ear bearing inter node is longitudinally grooved, to allow proper positioning of the ear head (cob). The upper leaves in maize are more responsible for light interception and are major contributors of photosynthates to grain. Due to the sequential development of the maize ear from the base to the tip and the variation in photosynthate availability to each kernel, seed from a single ear can fall into many size/shape categories. Large-round classes usually come from the base of the ear, flats from the center, and small-round seed from the tip (Lehoczky et al., 2013).

Maize has an erectile canopy architecture compared with the planophile architecture of broad leaf legumes like dry bean and soybean. This means that light can easily penetrate through the canopy thus allowing weeds to grow, especially in the early stages of growth when canopy cover is low. Moreover, the lower plant population densities used in rain–fed farming and for green mealies mean that this phenomenon is more amplified, hence weeds become a real problem.

SC701 is a popular hybrid variety in KwaZulu-Natal among small-scale farmers who still depend on rain–fed agriculture. The seed is usually planted in late spring or early summer. The SC701 variety is a high yielding variety and has good heat and drought tolerance capabilities making it an optional variety for rain–fed production. SC701 has a large cob size which is the most important selection criteria by farmers for green mealies production (Fanadzo et al., 2009). The maturity of SC701 hybrid is usually between 138 and 150 days, making it a medium to late maturing hybrid.

1.4 Weed-Crop Competition and Management

Weed competition remains a major cause of concern to global food production. Crop-weed competition emanates from the fact that weeds compete directly for resources, such as light, water and nutrients, thereby limiting crop growth and productivity. Similarly, crop-weed competition can be viewed as a series of resource dependent and resource independent processes that are interrelated (Rajcan et al., 2004). While there is no doubt that resource limitation has been a major factor driving yield losses from weed competition, resource independent effects, including light and hormonal signalling, may also play important roles in determining the onset and outcome of resource dependant competition (Page et al., 2011, Baldwin et al., 2007).

While it is generally believed that crop-weed competition begins shortly after crop emergence (O'Donovan et al., 1985), competition can actually start even before emergence. When a field is overrun by weeds, the crop may fail to emerge due to competition from the weeds' roots with germinating seeds for soil water and nutrient interfering with germination and hence emergence. At this stage (before emergence) the crop's ability to quickly emerge (vigour) and establish ground cover will determine if the crop is able to suppress weed competition. A low vigour hybrid will generally emerge slowly and therefore may be easily out–competed by weeds at the establishment stage. However, the most severe yield losses have been reported to occur when weeds emerge with the crop (O'Donovan et al., 1985). Yield potential is usually lost during this period; in most cases the crop will not recover from the yield losses even if proper weed management is done later on in the crop cycle. Yield losses caused by crop–weed competition, often occur regardless of whether other good agronomic practices such as proper tillage practice, fertilizer application, uniform planting space and planting depth, are done.

In South Africa, inadequate weed control leads to poor maize yields on small-scale farms (Joubert, 2000). Previous studies have shown that failure to properly manage weed competition in crops results in yield losses ranging from 30% (Joubert, 2000) to 70% (Teasdale, 1995). The inability of farmers to purchase herbicides due to their high cost and low levels of technology available to farmers limit their ability to effectively manage weeds (Chikoye et al., 2002). In the KwaZulu-Natal province, weed control through the use of herbicides is commonly practiced and/or integrated with other weeding treatments by commercial farmers while small-scale farmers mainly depend on hoe weeding (Walker and Schulze, 2006). Most farmers find it laborious to cope with aggressive and persistent annual weeds (Mkile, 2001, Mashingaidze, 2004). Under such cases, it may be beneficial if farmers could be advised on critical periods during which they must weed. An understanding of the critical period for weed control would reduce labour demand for the rural farmer.

Different studies have examined the potential impact of weeds on crop growth and development (Rahman et al., 1996, Rajcan et al., 2004, Liu et al., 2009, Markham and Stoltenberg, 2009). However, none of these studies was done for maize green mealies and most of them were done outside Africa. Further research is needed in order to better understand weed-crop competition for resources. This may also help to understand the role of the many small, but cumulative processes that are responsible for yield losses in crop production.

1.4.1 Weed management in maize

With the exception of factors such as soil fertility and water, competition from weeds has also been suggested as another limiting factor to increasing yield in maize production systems (Rajcan and Swanton, 2001, Subedi and Ma, 2009). Weeds compete with the maize plant for water, nutrients, space and light thereby reducing yield and profitability (Thomas et al., 1998). The effect of weeds on maize yield depends on the crop growth stage, weed population or density, the availability of water and nutrients and the weed species. The common weed species found in maize fields include couch grass (*Cynodon dactylon*), yellow nutsedge (*Cyperus esculentus*), Horse purslane (*Trianthema portulacastrum L*), goat weed (*Ageratum conyzoides*), (*Nicandra physaloides*) Jimsonweed *(D. stramoium L.*) and common cocklebur (*X. strumarium L.*) (Fanadzo, 2007, Karimmojeni et al., 2010).

Weeds can deprive the crop of 30-50% of applied nutrients and about 20-40% of available soil water (Rajcan et al., 2004). The most critical period for weed competition is during the first four to six weeks after crop emergence. Even small weeds during the first week after emergence can reduce grain yield substantially (Page et al., 2010). Previous studies have suggested critical periods for weeding for maize production for optimum yield. Keller et al. (2012) observed that in Benin and Germany, yield losses increased significantly with increased duration of weed competition in maize fields. They concluded that the best time for weeding was from the fourth leaf stage until flowering. Hall et al. (1992) defined the critical period for weeding maize in southern Ontario as between the third and 14th leaf stage. However, the physiological reasons why maize was most vulnerable between the third and 14th leaf stage as suggested by Hall et al. (1992) have not been fully explored. In South Africa, approximately 2% of maize potential yield is lost for every day that weeds remain in the field during the period 30-60 days after sowing (Marais, 1985).

There are limitations associated with defining the critical period for weeding in maize namely; (i) critical period for weeding is cultivar specific; (ii) it is inconsistent across climates and locations, and (iii) it is weed species specific. Some of these limitations can, however, be overcome if the critical period is determined based on mixed weed population rather than one particular weed species and by using growth stage of a crop rather than calendar days to define the critical period (Hall et al., 1992). However limited studies have shown the critical weeding period for optimum maize yield of a specific cultivar.

Application of empirically determined critical periods for weeding in maize could be enhanced by an understanding of the effects of weeds on growth and development of the crop in view of the large degree of variation in crop cultivars, environmental factors and weed species in maize production. Similarly, and although early weeding is critical to producing a good yield in rain fed agriculture, late weed control is also important in preventing weeds from flowering and producing seeds. These would affect the crop and increase weed load in subsequent planting seasons. Harvesting will also be made easier if the crop is weed free.

1.5 Effect of Weed Competition on Maize Growth

1.5.1 Plant height

Depending on the variety and growing conditions, plant height of maize varies from 0.3 m to 7.0 m (Gyenes-Hegyi et al., 2002) especially, in the tropical climates where the growing season may be as long as 11 months (Kgasago, 2006). The impact of weed infestation on plant height in maize depends on the growth stage of the maize and weed density. For instance, Tollenaar et al. (1994) observed that the impact of weed on plant height is mostly during the grain filling period when there is sustained leaf photosynthesis and hence increased dry matter partitioning. Increased weed density has been reported to reduce plant height (Sikandar et al., 2007, Subedi and Ma, 2009). Maize planted in unweeded plots tended to grow 17% taller than the weeded plots due to competition for solar radiation between the maize and weeds (Silwana and Lucas 2002). Plant height is a crucial factor for radiation interception (Stewart et al., 1997). Uncontrolled weeds from the fourth week onward will likely result in shading of lower leaves thus impeding radiation interception (James et al., 2000). The changes in plant height in weed infested maize plots could be attributed to differences in cell enlargement and enhanced leaf senescence (Rajcan and Swanton, 2001). Moreover, since internodes account for maize height, changes in maize internodes as a result of competition for soil water, solar radiation and nutrients by weeds will influence the plant height. Weed competition in maize production may also affect the length of internodes probably by preventing the elongation of developing cells. Maize plants get taller as mutual shading increases, although varietal variations influence this characteristic

(Yokozawa and Hara, 1995). Another important factor that affects plant height in weed infested maize is the cultivar.

Hossain (1992) and Oteui et al. (1995) found that some weed like *Amaranthus spinosus* and *Chenopodium album* had an effect on maize and barley growth. They found that when these two weeds were allowed to grow under greenhouse conditions, maize plant height was 20% lower than in plots without weeds. Similar results were obtained by (Cathcart and Swanton, 2004, Begna et al., 2001). Gab-Alla et al. (1985) observed that there was a linear decrease in plant height with increase in weed-maize competition duration. While most of the above literature expatiates the relationship between weeds and maize height, there appears to be no reports on the influence of critical period for weeding on maize plant heights. Moreover, farmers need to know when the presence of weeds affects the growth of maize most so as to know when to remove the weeds. Furthermore, no studies have shown if there is any differences in the yield of different seed shapes (Flat or Round) of drought sensitive maize in the presence and absence of weeds.

1.5.2 Leaf area development

Leaf area index (LAI) Leaf area index is estimated from the leaf characteristics and it is the measure of the photosynthetic capacity of the plant (Stewart et al. 1997). It defines the ability of a crop to intercept solar radiation. Thus, any reduction in LAI below the optimum implies less radiation interception and influences yield directly (Rajcan et al., 2004). Variations in canopy characteristics such as LAI in maize are large and have practical implications for weed management. For instance, Pataky (1994) reported differences in vertical leaf area distribution among 11 hybrids, with total leaf area ranging from 2 540 to 4 660 cm^2 per plant. Higher maize maximal leaf area index (LAI) from anthesis to harvest conferred greater suppression of wild proso millet (*Panicum miliaceum L.*), and LAI at the 120 to 150 cm height was negatively correlated to weed growth and fecundity (Williams et al., 2007). Similarly, Williams II and Lindquist (2007) reported that weed interference reduced maximum maize LAI and canopy growth rate. They observed that, maximum LAI was reduced by 23 to 33% due to weed interference while absolute canopy growth rate was reduced by 11 to 40% due to weed interference. Hall et al. (1992) and Evans et al. (2003) observed similar leaf area reductions (11% to 40%) due to weed interference from. The reduction in LAI in weed infested plots, relative to weed-free indicates reductions in maximum maize leaf area may have been a result of weed interference inhibiting leaf emergence or leaf area expansion, as opposed to accelerating leaf senescence (Williams II and Lindquist, 2007). Moreover, low leaf area in weed infested plots might be attributed to higher weed population in these plots competing for available resources.

Reduction in maize LAI during silking to two-three weeks after silking reduces the number of kernels being set. In addition, reduction in LAI during the grain filling period affects kernel mass. Kernel set and grain filling processes represent sinks in terms of source-sink relationships while LAI represents the source. Thus, lower LAI will impose source limitations on the sink translating to reduced kernel set and mass due to reduced assimilate availability. Both kernel mass and number are components of yield which ultimately means low yield as a result of poor kernel set and grain filling. High weed pressure reduced LAI of maize at silking by 15% compared to weed-free control (Karimmojeni et al., 2010). In another study, weeds reduced maize LAI during the grain filling but not at silking (Thomas and Howarth, 2000). In general, LAI is an important indicator of weeds' competitiveness (Tollenaar and Wu, 1999); yield losses in maize resulting from competition for solar radiation are better explained through the reduction in LAI. Plants with higher LAI are more competitive as a result of being able to capture more photosynthetically active radiation (PAR) (Rajcan et al., 2004).

1.5.3 Grain yield and plant biomass

Maize grain yield is mainly determined by kernel number per unit land area (Sikandar et al., 2007). This grain yield component is positively related to crop growth around silking (Gouse et al., 2006, Tollenaar and Wu, 1999), and biomass allocation to reproductive organs (Rajcan and Swanton, 2001). Since biomass partitioning to the ear and kernel set responds to the amount of resources available for each individual plant, expression of the relationship between kernel number and growth rate on an individual plant basis may have greater physiological significance (Yokozawa and Hara, 1995).

Competition from weeds early in the development of maize remains one of the most serious and widespread production problems facing smallholder maize producers in Southern Africa (Walker and Schulze, 2006, Mnkeni, 2007, Mashingaidze, 2004). Weed competition in the initial stages of crop growth can have profound effects such as stunted growth and/or crop failure (Chivinge et al., 1997). The time of weed emergence relative to the crop is an important parameter in estimating yield losses due to weed competition (Fanadzo, 2007). Weeds that emerge together with the crop or shortly thereafter cause greater yield loss than weeds that emerge later in the growth cycle of the crop (O'Donovan et al., 1985, Silwana and Lucas, 2002). Importance of timing of weed emergence relative to the crop is described by the critical period for weed control (Rajcan and Swanton, 2001). The critical period is useful in defining the crop growth stages most vulnerable to weed competition. The critical period is defined as the number of weeks after crop emergence during which the crop must be weed-free in order to prevent yield losses greater than 5% (Karimmojeni et al., 2010, Rajcan et al., 2004). The critical period for maize ranges from 1 to 8 weeks after the crop emerges (Thomas et al., 1998, Rajcan et al., 2004, James et al., 2000).

Similarly yield losses from weed competition are on a per-unit-area basis, they are the direct result of changes in biomass accumulation and partitioning. In maize, the proportion of total aboveground biomass at maturity allocated to grain (harvest index) is relatively stable for large and medium size plants, but then declines rapidly in smaller individuals (Keller et al., 2012). Kernel number is associated with the rate of plant dry-matter accumulation and partitioning to the ear during a critical period of three to four weeks centred on and including silking (Tollenaar and Wu, 1999). If the plant growth rate around silking falls below a threshold, then kernel set fails resulting in barrenness. Thus, reductions in maize grain yield caused by weed competition are as a result of declining plant growth rate around silking, leading to lower kernel set and, to a lesser extent, low kernel mass. The physiological mechanisms causing the observed yield losses, weed control studies need data on crop yield components (i.e., kernel number and mass) and biomass partitioning at physiological maturity. Currently, only a few weed control studies have collected such data (Tollenaar and Wu, 1999).

1.5.4 Nutrient

Competition for nutrients must take into account the temporal dynamics of nutrient uptake by crop and weeds, whether or not the uptake and assimilation of the nutrient are energy dependent, and the interdependency of soil–nutrient relationships. Nitrogen uptake by maize occurs from the early seedling stages of development to three to five weeks after silking. Nitrogen uptake is an energy dependent process relying upon assimilate supply from shoots to the roots. This energy is provided by photosynthesis. During vegetative dry mass accumulation, maize roots are the major sink for photo-assimilates. Prior to silking, approximately 65–80% of the plant total N is taken up by the roots (Rajcan et al., 2004). After silking, less assimilates are supplied to the roots as the kernels become the major sink for photo-assimilates. As a consequence, root growth and N uptake decline. Even though N uptake during the grain filling period represents a smaller proportion of the total plant N (20–35%), its role in determining final yield is important.

Several studies have shown that high yielding maize genotypes take up N for a longer time during grain filling in comparison to low yielding genotypes (Rajcan and Swanton, 2001, Tollenaar and Wu, 1999). Prolonged N uptake during grain filling is associated with extended leaf area duration and greater rates of dry matter accumulation, resulting in larger yields (Keller et al., 2012, Tollenaar and Wu, 1999). It has been hypothesized that such genotypes are able to maintain root growth and N uptake together with grain filling (Rajcan et al., 2004). Therefore, an adequate N supply during the period of N uptake by maize is essential in order to achieve optimum yields. The presence of weeds, however, throughout the life cycle of maize will alter both the available N pool in the soil and dry matter allocation within the plant. A reduced pool of N in the soil will result in enhanced development of N deficiency symptoms, which include general chlorosis and enhanced leaf senescence; mostly in older leaves. There is reduced ear-leaf chlorophyll concentration at silking of maize grown under high weed pressure relative to weed-free maize (Tollenaar and Wu 1999). Enhanced leaf senescence in maize under high weed pressure than under weed-free conditions was also observed (Tollenaar and Wu, 1999). Decline in chlorophyll concentration and acceleration of leaf senescence under limited N supply will reduce the total assimilate production of a maize crop and eventually yield.

Nitrogen deficiency symptoms develop earlier in maize when grown in association with weeds compared to weed-free conditions. This would imply more depletion of soil N under weedy conditions. Teasdale (1995) reported that the root dynamics of maize growing in competition with weeds would be similar to the root dynamics of maize growing under low N. Moreover, there are indications that under weed infested conditions maize roots may be less developed than under weed-free conditions (Thomas et al., 1998). Dry matter allocation in maize is likewise not determined solely by nutrient competition.

Competition for nutrients between maize and weeds is influenced by type and amount of nutrient available, amount of precipitation and weed species. The yield of maize was reduced by weeds more under limited than under luxury N supply (Stewart et al., 1997). Under N limiting conditions, maize yields were 47% lower under weed infested than weed-free conditions. Under high N levels, however, yields were only 14% lower under weed infested than under weed-free conditions (Stewart et al., 1997). The weed species involved, however, can alter the outcome of competition for N. (Rajcan et al. (2004) reported that a luxury N and potassium K supply did not overcome the effects of quack-grass competition. Little is known of the effects or interactions of phosphorus P and K on the outcome of weed competition with maize. Similarly, Subedi and Ma (2009) found that weeds were more sensitive to low P and K levels than the crop species. Frequently, soil water affects nutrient availability (mobility, mineralization), thus the outcome of maize–weed competition for nutrients varies with soil moisture content (Rajcan and Swanton, 2001). Nutrient competition between maize and weeds has received only little attention. Most studies have focussed on the above-ground symptoms of nutrient and/or water deficiency.

1.5.5 Photorespiration

Plants lose large portions of their fixed carbon dioxide (CO_2) during illumination by photorespiration. Since photorespiration is often much faster in terms of CO_2 production than dark respiration, it often lowers plant productivity (Rajcan and Swanton, 2001). The productivity of plants (dry mass per unit of ground area) is depending on the gross CO_2 assimilation during photosynthesis minus the CO_2 released during respiration. This wasteful portion of respiration could cause diminished productivity (Rajcan et al., 2004). Most crops and weeds attain their maximum photosynthetic rates at high levels of irradiance (Rajcan and Swanton, 2001). In a mixed crop–weed community, mutual shading of leaves causes reduction of available photosynthetic photon flux density (PPFD), which results in reduction of photosynthetic rates. The latter reduces dry matter accumulation of both crop and weed. The intensity of crop–weed competition for incident PPFD is mainly influence by the specific crop–weed association. Maize seems to be a good competitor for incident PPFD and its canopy captured light primarily above the topmost ear by the youngest and more efficient leaves (Rajcan et al., 2004) and less than 10% of incident PPFD reaches canopy strata below 1 m. Most of the weed flora in a maize canopy at silking and thereafter, however, is below 1 m (Tollenaar and Wu, 1999). Thus, direct competition for incident PPFD by weeds in a maize canopy is relatively weak, 13% of the incident PPFD in a maize canopy was intercepted by weeds under high weed pressure (Tollenaar and Wu, 1999). Even in a weed-free situation, maize leaves below the topmost ear are shaded by the upper leaves of the maize canopy and are also older than the leaves above. Hence their photosynthetic rates are lower than that of the leaves above. This indicates that yield loss of a maize crop due to competition from weeds for incident PPFD probably cannot be explained by reduced photosynthetic rates of lower maize leaves shaded by weeds.

1.5.6 Soil Water

Competition for water between crop and weeds occur as a result of reduced water availability to the crop due to the presence of weeds (Thomas et al., 1998). Prolong weed competition in maize reduced soil moisture which in turn contributed to reduced grain yield (Grant et al., 1989). The magnitudes of water stress on maize depend on the developmental stage at which the stress occurred, duration and severity of the stress (James et al., 2000) and weed species involved. Water deficits during the accumulation of dry matter can limit the height, vegetative biomass (Stewart et al., 1997) and rate of leaf appearance, but not necessarily the yield. Yield, however, will be reduced if water stress occurs during pollination (Marais, 1985, James et al., 2000). Maize is more vulnerable to moisture stress during reproductive rather than during early vegetative stages of development. Limited water stress during vegetative growth may lead maize to withstand water stress during pollination resulting in less yield loss (Grant et al., 1989, Fanadzo, 2007). The duration of water stress will determine the physiological response of maize and the magnitude of yield reduction. Plants exposed to water stress for several hours respond by a reduction in the transpiration rate through a lowering of the leaf water potential and closing of stomata. Stomatal closing will affect the rate of leaf photosynthesis, which may influence the grain yield. However, under prolonged moisture stress whole plant photosynthesis is reduced with a possibility of permanent damage to the photosynthetic apparatus (Karimmojeni et al., 2010). The severity of this damage will affect total dry matter accumulation and allocation among various organs of the plant.

Under weedy conditions, maize will have lower leaf water potential, reduced leaf stomatal conductance and reduced leaf photosynthesis earlier than when grown in the absence of weeds (Tollenaar and Wu, 1999) because water availability under weedy conditions is limited. However, measurements of water content in the soil profile under weedy and weed-free conditions did not show differences in soil water content (Tollenaar and Wu, 1999). The presence of weeds lead to the development of water stress symptoms may not be caused by water availability but rather by the reduced ability of the root system to absorb water (Thomas and Howarth, 2000).

Maize respond to the presence of weed by accumulating more dry matter (DM) in the shoot than in the root (i.e., the root/shoot ratio is reduced) (Rajcan and Swanton, 2001). During vegetative growth, weeds and maize may not show signs of competition for water but root/shoot ratio of both weeds and crop would be altered. Maize grown together with weeds may have a less developed root system compared to maize grown under weed-free conditions. Thus, the more limiting factor in water uptake during reproductive DM accumulation may be a less developed root system, rather than water availability per se. Another possibility is that exudates of weed roots may contain toxins that can inhibit the root growth of maize and this happen with some specific weeds such as common cocklebur (*Xanthium strumarium L*), yellow nutsedge (*Cyperus rotundus*) and foxtail species (*Setaria viridis*). In addition, some weed species such as knapweed (*Centaurea maculosa*), witch weed (*Striga spp*) and crabgrass (*Digitaria velutina*) are more tolerant of water stress.

1.6 Maize Planting Season in South Africa

Rain-fed cropping systems in the semi-arid tropics face challenges of water deficits, and uncertainty as the major limiting factors to crop production (McCann, 2005, Hassan, 2006). A common characteristic of semi-arid regions is that they normally receive low rainfall amounts ranging 300 – 600 mm. In South Africa, rain-fed crop production is feasible in summer, in which 80% of rainfall is received whilst the rest falls in winter (Marais, 1985). Although maize is adapted to vary climatic conditions.However, during the summer period, rainfall occurrence is usually very erratic, and poorly distributed (Marais, 1985). In such environments, rainfall occurrence is primarily important to farmer decision making such as what to plant, how and when to plant (Mnkeni, 2007). The decision on when to plant is very important because of the very great differences in weather at planting time between seasons and within the range of climates (Oteui et al., 1995). For instance, and based on varying weather conditions in South Africa, the broad optimum planting dates are suggested to be from the beginning of October to the first week of November for cooler eastern producing areas and from the last week in October to mid-November; for drier western areas from the last two weeks in November to mid-December for central regions.

The ability of high yielding maize cultivars to be planted twice within winter and summer seasons has not been explored. It has been observed that most popular high yielding maize hybrids with South African farmers are usually late maturing (Modi, 2004). High yielding maize planted early in the rainy season mostly develops to physiological maturity within 138-145 days after sowing. However, the comparism between winter and summer planting seasons on physiological and morphological characteristics of high yielding maize in relative warm climatic region and semi-arid tropics such as Kwazulu-Natal are yet to be fully studied. This is because there can be very large differences in the pattern of response to planting time among cultivars.

1.7 Effect of Early and Late Planting on Maize Development

1.7.1 Grain yield

Maize planted earlier develops better and has a higher yield potential because the vegetative period of its development occurs in the cooler part of the season when water stress is less likely. The optimum uses of limited growing period for maize is essential to maximize grain yield in short season areas (Corke and Kannenberg 1989). Generally, there are many benefits related to planting early compared to late planting and these include a long growth duration that allows a greater choice of hybrid maturities and wider opportunities for replanting decisions. Again, earlier planting tends to place the tasseling and silking period ahead of the greatest risk of water stress and drought damage (Oteui et al., 1995). Early planting date could contribute significantly to higher maize yields (Imeokparia and Okusanya, 1997). Higher yield is not the only advantage of early planting because other benefits can also be achieved such as harvesting earlier in the season when conditions are usually better and field and time losses can be minimized (Kgasago, 2006). In addition, early planting increases net returns without adding production costs.

On the other hand late planting or planting after the certain optimum period has been reported to consistently result in lower yields. Delayed planting shortens the effective growing season for maize, increasing the risk of exposure to lethal cold temperatures late in the season before grain maturation. According to Kgasago (2006), yield reduction in late plantings could be attributed to a short growth duration, insect and disease pressure, heat and moisture stress during pollination. Chivinge et al. (1997) and Oteui et al. (1995) reported that delayed plantings are generally accompanied by increased temperatures during the growing season, which accelerate crop development and decrease accumulated solar radiation, resulting in less biomass production, kernel set and grain yield.

In principle, a delay in planting beyond a given date results in a progressive reduction in the potential yield of the crop, because an increasing proportion of the available solar radiation will not be intercepted by the crop canopy. In practice, yield does normally decline with delay in planting due to yield penalties encountered. However, the results of planting date experiments can be highly inconsistent between seasons (winter and summer) and sites. For example, it is not unusual for a relatively late sown crop to out yield the control crop sown within what would be considered to be the optimum period (Oteui et al., 1995). There are several reasons for such inconsistencies and unexpected results. First, the soil conditions at different planting dates will inevitably be different and unfavourable conditions (excess or deficiency of soil water and serious incidence of disease) can occur at almost any point during the normal planting dates.

Consequently, the observed differences in the performance of crops sown on different dates are commonly a reflection of differences in established plant density. Secondly, crops sown at different dates pass through each developmental stage at slightly different times and, therefore, under different environmental conditions (especially photoperiod and temperature), thus any one of the developmental stages which determine the components of yield could conceivably occur under more or less favourable conditions in late-sown crops. For these reasons, it is not easy to carry out a critical comparison of the grain yields and their components of the different crops in a sowing date experiment. Scarsbrook and Doss (1972) reported that yield of maize is a function of many plant and environmental factors which are often interrelated.

1.7.2 Plant biomass

Dry mass of plants consist of 5-10% of minerals and nitrogen in the soil. Variation in maize planting time modifies the thermal conditions during growth. The amount of incident radiation and the proportion of this radiation that is intercepted by the crop directly determine crop growth rate (Markham and Stoltenberg, 2009). Markham and Stoltenberg (2009) reported that delays in planting date determined important reductions in the amount of incident radiation accumulated from emergence to silking, because it hastened development. Inversely, high temperatures during early growth of late plantings hastened leaf area development as shown by their high early percentage photosynthetic active radiation (PAR) interception values. Several authors reported similar temperature effects on leaf appearance rate and on leaf expansion in maize (Sheperd et al., 1991, Rajcan et al., 2004).

Oteui et al. (1995) reported that at the grain filling stage, plants exposed to low radiation and low temperature in late plantings, compared to early plantings, will result in decreased dry matter production. Late plantings also showed a higher non-structural carbohydrate concentration in stems at mid-grain filling than the early plantings. This suggested that low temperatures during grain filling in late plantings limited kernel growth as well as crop photosynthesis. Thus, the ratio between final kernel number and dry matter at silking dropped dramatically for the late plantings, indicating a predominance of vegetative growth over reproductive growth.

In general, late plantings will result in high crop growth rates during the vegetative period because of high radiation use efficiency (RUE) and high percentage radiation interception, but conversely result in low crop rates during grain filling because of low RUE and low incident radiation. The inverse holds true for early plantings (Markham and Stoltenberg, 2009). In addition, Oteui et al. (1995) found that in late plantings, both solar radiation and temperature decline during grain filling. Thus, lowered solar radiation resulted in grain growth in excess of biomass production, indicating a possible source limitation. On the other hand, low temperature may have a negative effect on kernel mass through reductions in both radiation use efficiency and biomass partitioning to the grains (du Toit et al., 2002).

1.7.3 Physiological maturity

Tollenaar and Wu (1999) found that the time from silking to physiological maturity lengthened with delay in planting dates. This was because cool temperatures late in the season of the late planted crops prevented true maturity since grains never formed a true black layer. Sheperd et al. (1991) found that delayed planting increased the thermal time interval from planting to mid-silking but decreased the thermal interval between mid-silking and black layer formation. (Sheperd et al., 1991) also reported that thermal intervals between plantings and black layer decreased as planting was delayed from early to late planting. Thus late planting reduced cumulative intercepted light from silking to physiological maturity mainly because of their low values of daily incident radiation (Tollenaar and Wu, 1999). On the other hand, radiation use efficiency (RUE) for late planting was high in the early growing stages and low during the cool grain filling period. The opposite was true for early planting that showed low RUE from emergence to silking and sustained during most of the grain filling period when temperatures were more favourable for the photosynthetic process (Corke and Kannenberg, 1989). In addition, the period between emergence and anthesis of maize hybrids planted earlier in the season can be up to two weeks longer than when the same cultivar is planted later (Corke and Kannenberg, 1989). During this extra period, plants will intercept and store more solar radiation because the lower temperatures limit their growth and consumption of this energy. As a result of this slower pattern of development, early planted maize plants are smaller and less leafy at anthesis (Oteui et al., 1995).

Stewart et al. (1997) reported that delayed planting increased growing degree days (GDDs) to black layer for three hybrids in a drought year but decreased GDDs to black layer for the same three hybrids in the following year under less stressful conditions. The GDDs system gives a reliable estimate of thermal time required for vegetative development (Stewart et al., 1997). Estimates of thermal time required for grain filling (period between silking and maturity) vary considerably, however, with the GDD system frequently overestimating thermal time required for grain filling. A better understanding of the phenological response of maize to thermal time as planting is delayed is necessary to improve the accuracy of hybrid maturity selection for late planting situations.

1.8 Conclusion

Maize is no doubt one of the major sources with regards to bridging the impeding food scarcity as a result of climate change in sub-Saharan Africa. However, competition from weeds and the inability of small holder farmers to plant twice green mealies of relatively high yielding maize within a growing season still remains one of the most serious production problems in Southern Africa (Mnkeni, 2007, McCann, 2005). In order to realize the potential of more ecological approaches to weed management that would reduce reliance on herbicides, the underlying processes of weed and maize competition must be understood. Weed competition in maize has been studied from an applied aspect by defining the critical time for weed control (FAOSTAT, 2012) and associated weed threshold values (Rajcan and Swanton, 2001). Researchers have devoted little energy to determine why a particular timing for weed control is optimal or why a particular weed threshold can be tolerated.

Similarly, the ability of planting green mealies of high yielding maize hybrids twice in relatively warm climatic regions of South Africa is still not known. Generally, high yielding maize hybrids and their composites are often more promising in dryland environments. However, more emphasis has been placed on characterizing hybrids to their level of tolerance for easy selection by farmers rather than the possibility of planting green mealies twice within a particular growing season. In addition, the fact that much attention is currently being focused on developing hybrids with high yield stability across a wide range of environments than on improving agronomic practices such as critical periods for weeding and planting dates of existing hybrids necessitates this current study. Understanding the optimum weeding time and planting dates for high yielding green mealies hybrids will contribute to improve food security.

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CHAPTER 2

Effect of seed size and shape on germination characteristics of SC701 maize hybrid under different temperature regimes

2.1 Introduction

Farmers in KwaZulu-Natal plant their maize at different times ranging from early to late planting. The earlier planted crop is often sown in a dry cold seedbed, while optimum and late plantings usually occur during summer when the soil is often warm and wet. Under these conditions, temperature may prove to be an impediment to successful stand establishment. Therefore, testing the germination characteristics of seed at different temperatures is important even before it is planted in the field.

Seed quality characteristics are important for maize production because they determine the density of crop stand and consequently yield. Seed quality is defined as the viability and vigour of the seed (Copeland and McDonald, 2001, Tekrony et al., 2005, Shirin et al., 2008) it also include its physical quality and health. It is an important consideration because it influences field emergence, seedling establishment and subsequent performance of the resultant plant (Moreno-Martinez et al., 1998, Abbasian et al., 2013). Germination of seed may vary at different temperature regimes (Bosci and Kovacs, 1990). This is because temperature is a modifying factor in germination since it can influence available soil water and nutrient supply necessary for maize growth and development (Keeling and Greaves, 1990, Bosci and Kovacs, 1990). Temperature response (for crop development) in maize is widely defined in terms of base (T_{base}), optimum (T_{opt}) and maximum (T_{max}) temperatures. The base ($T_{base)}$ and maximum ($T_{max)}$ are the temperatures below and above respectively which crop growth and development ceases while T_{opt}, is the temperature at which development proceeds optimally.

A base temperature of 10°C and an optimum temperature of 30°C are widely reported in the literature for maize (Bosci and Kovacs, 1990, Bircha et al., 2003). According to Idikut (2013), optimum temperature for maximum seed germination was 30°C, and T_{opt} ranging between 17°C and 30°C produced high crop stand or seed germination and emergence. Furthermore, many studies on the effect of temperatures in maize have shown a strong, negative relationship between low temperatures and germination rate, emergence time, and germination uniformity (Idikut, 2013, Kırtok, 1998, Bircha et al., 2003, Keeling and Greaves, 1990).

Seed size and shape are also important characteristics that affect growth of plants (Shashdhara et al., 1988, Mazur and Feranec, 1994, Copeland and McDonald, 2001, Enayat Gholizadeh, 2012). Maize seed size and shape varies considerably due to genetics, environmental conditions (low or high temperature, soil moisture and fertility) during growth and development, especially during the grain filling stage (Hussaini et al., 1984). These variations are affected by various environmental factors such as nutrition of the maternal plants and genetic resources (Tekrony et al., 2005). Also, its location on the ear plays an important factor in deciding seed size (Graven and Carter, 1990). Conventionally, maize seed is categorized by size and shape, large and small, flat and round, respectively. While local small-scale farmers do not differentiate between the shapes and sizes of seeds, previous studies have shown that germination and vigour of maize are significantly affected by seed size and shape with different results.

Rammana (1967) found that there was greater seedling emergence among the large seeds than from among medium and small seeds. Halim et al. (1969) studied the plants grown from seeds collected from the top, middle and bottom portions of the maize cob. They found that the seeds from middle portion of the cob recorded highest seedling emergence. Hunter and Kannerberg (1972) could not find any difference in the germination percentage of maize in relation to seed size and shape. Recently, Tekrony et al. (2005) reported that germination rate and vigour indices were lower for round than flat seeds.

Among the maize hybrids in Southern Africa, SC701 is one of the most popular hybrids among small-scale farmers who still depend on rain fed agriculture. The SC701 hybrid is a high yielding variety with fairly good drought tolerance, and hence an optional variety under rain fed farming. This variety has a large cob size which is an important selection criteria by farmers for green mealies production (Corke and Kannenberg, 1989). While few studies have studied seed quality of SC701 hybrid using standard germination test (Mabhaudhi and Modi, 2010), there is currently limited literature describing germination and establishment of SC701 under different temperature regimes and issues related to seed size and shape. Currently, studies that have evaluated these three factors (temperature, seed shape and size) on maize hybrids have done so independently, with none evaluating their interactive effect on seed germination. The present study therefore aimed at investigating the interactive effect of seed size and shape on germination characteristics of SC701 hybrid under different temperature regimes.

2.2 Material and Methods

2.2.1 Planting material

Seed of SC701 varieties, round and flat, was obtained from McDonalds Seed Company, Pietermaritzburg, South Africa. The seed was then visually characterized into two seed sizes, small and large, to come up with four seed groups: Round large, Round small, Flat large and Flat small (Figure 2.1). The 100 grain mass of these four 'seed groups' was then determined.

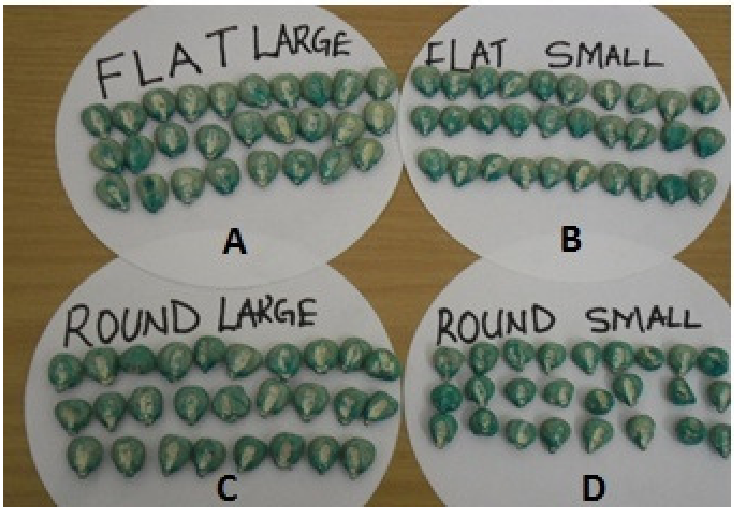

Figure 2. 1: Four seed groups used in this study differing in shape and size of SC701 Maize (A= Flat large, B= Flat small, C= Round large, and D= Round small).

2.2.2 Standard germination test

The standard germination test was done using a split-plot design with temperature regimes as the main factor and seed groups as sub-factors, replicated four times. There were four temperature regimes, 30°C and 20°C constant temperatures, and two alternating temperatures, 30/20°C and 15/20°C (12/12hrs). The four SC701 'varieties' were as described in Section 2.2.1. The standard germination test was conducted by germinating four replicates of 25 seeds from each 'seed group' between double layered paper towels (AOSA., 1992). The rolled paper towels were put in sealed plastic bags to avoid moisture loss and incubated in four different Labcon growth chambers model L.T.I.E set at the respective temperature regimes, 20°C, 30°C, 15/20°C and 30/20°C, for 8 days. Daily counts of germination were based on defining germination as radicle protrusion of 2 mm. Observations for final germination percentage, on day 8, were made according to AOSA. (1992) guidelines. Upon termination of the experiment, 10 seedlings from each seed group were randomly selected and used to determine root and shoot length, root: shoot ratios, fresh and dry mass. Seedling dry mass was determined by oven-drying seedlings at 70°C for 72 hours and weighing them afterwards.

Germination rate (GR) was calculated according to Krishnasamy and Seshu (1990):

Germination rate (%) = (Number of seed germinated at 48 hours / number of seed germinated at 120 hours) X 100 Eq. 2. 1

Germination velocity index (GVI) was calculated according to Maguire (1962) formulae:

$GVI = G_1/N_1 + G_2/N_2 + ... + G_n/N_n$ Eq. 2. 2

where: GVI = germination velocity index,

$G_1, G_2 \ldots G_n$ = number of germinated seeds in first, second… last count, and

$N_1, N_2 \ldots N_n$ = number of sowing days at the first, second… last count.

Mean time to germination (MGT) was calculated according to Bewley and Black (1994):

$MGT = \sum Dn / \sum n$ Eq. 2. 3

where: MGT = mean germination time,

n = the number of seed completing germination on day D, and

D = number of days counted from the day of sowing.

The seed vigour index was calculated according to the formula by (Abdul- Baki and Anderson, 1973) :

Seed Vigour Index (VI) = (shoot length x germination percentage) Eq. 2. 4

2.2.3 Description of statistical analyses

Data collected were analysed using analysis of variance (ANOVA) from GenStat® (Version 14, VSN International, UK) statistical package. Means were separated using LSD at the 5% level of significance (Appendix 1).

2.3 Results

2.3.1 Standard germination test

Results of the standard germination test showed that there were no significant differences (P>0.05) among seed groups, temperature and their interaction with respect to final germination (Table 2.1). Highly significant differences (P<0.001) were observed for daily germination percentage among seed groups, temperatures and their interaction (Figure 2.2). All seed groups (Roundlarge, Roundsmall, Flatlarge, and Flatsmall) reached maximum germination after four days (Figure 2.2). The SC701 seed groups germinated relatively slower at 20/30°C compared to other temperature regimes. The Flatsmall seeds germinated faster compared with other seed groups across all temperature regimes; they were shown to germinate fastest at 30°C (Figure 2.2).

In terms of vigour, highly significant differences (P<0.001) were observed among seed groups, temperature and their interaction with respect to GR, GVI and VI. At constant temperatures, germination GR was higher at 30°C than 20°C while at alternating temperatures (15/20°C and 20/30°C), GR was zero (Table 2.1). At constant 20°C, Flatsmall seeds showed the highest (46.7%) GR which was statistically similar with Flatlarge seeds (45.3%). Whereas, Roundlarge had the lowest (17.3%) germination rate. At 30°C, all varieties reached their highest GR (53.3-64%) (Table 2.1).

The highest GVI (26.47) was observed for Flatsmall at 30°C and Flatlarge at 20°C and they were also statistically similar (Table 2.1). Similarly, the lowest GVI (10.81) was obtained for Roundlarge at the alternating temperature of 20/30°C (Table 2.1). For the seed vigour indices (VI), Roundlarge and Roundsmall and showed a decreasing trend while, Flatlarge and Flatsmall showed an increasing trend as temperature increased from 20°C to 30°C. At 20°C, VI ranged from 685 – 495 while at 30°C VI was lower and ranged from 733 – 267 (Table 2.1). No trend was observed for 15/20°C but all seed groups had highest VI at 20/30°C among the temperature regimes. Flatsmall seeds showed the highest VI at 20/30°C while Roundlarge had the lowest VI at 15/20°C.

Table 2. 1 Germination rate, germination velocity index, mean germination time, final germination percentage and germination vigour index of different SC701 seed groups incubated at temperature regimes.

Variety	**Temperature (°C)**	**^{u}GR (%)**	**^{v}GVI**	**^{w}MGT (Days)**	**^{x}FGP (%)**	**^{y}VI**
Roundlarge	20	17.30ab	16.53bc	5.00a	100.00a	633.00cde
	30	53.30d	21.47d	5.00a	100.00a	510.00abcd
	15/20	0.00a	14.06ab	5.00a	100.00a	232.00a
	20/30	0.00a	10.81a	5.00a	100.00a	593.00de
Roundsmall	20	28.00bc	20.61c	5.00a	100.00a	495.00abc
	30	64.00d	22.14d	5.00a	100.00a	267.00ab
	15/20	0.00a	13.6ab	4.933a	98.67a	674.00cde
	20/30	0.00a	11.02a	4.933a	98.67a	559.00e
Flatlarge	20	45.30cd	26.47d	5.00a	100.00a	665.00cde
	30	53.30d	26.25d	5.00a	100.00a	533.00bcd
	15/20	0.00a	14.31ab	5.00a	100.00a	250.00ab
	20/30	0.00a	13.25ab	5.00a	100.00a	718.00cde
Flatsmall	20	46.70cd	25.97d	5.00a	100.00a	685.00cde
	30	64.00d	26.47d	5.00a	100.00a	535.00bcd
	15/20	0.00a	16.31bc	5.00a	100.00a	355.00ab
	20/30	0.00a	12.35ab	4.9333a	98.67a	769.00cde
F Pr.		P<0.001	P<0.001	Ns	Ns	P<0.001
SED		5.90	1.443	0.0395	0.79	75.00
LSD $_{(P=0.05)}$		12.37	2.406	0.08338	1.668	153.20
CV (%)		31.90	7.60	1.00	1.00	6.30

^{u}GR= germination rate; ^{v}GVI =germination velocity index; ^{w}MGT= mean germination time; ^{x}FGP= final germination percentage; ^{y}VI = vigour index; Ns = No significant difference;

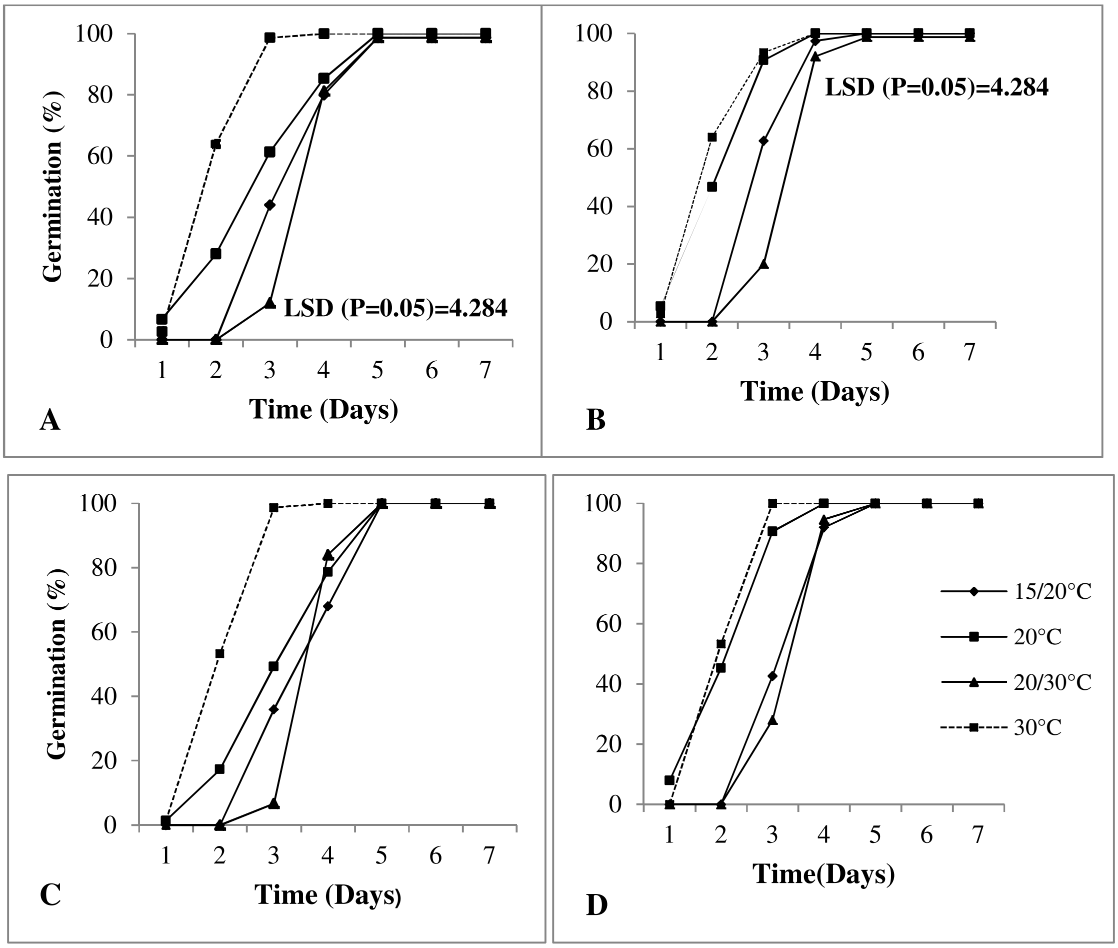

Figure 2. 2: Daily germination percentage SC701 seed groups A (Round small), B (Round large), C (Flat small) and D (Flat large) incubated at different germination chamber temperature regimes.

2.3.2 Seedling shoot and root length

There were no significant differences (P>0.05) among seed groups, temperatures and their interaction for seedling shoot and root length (Table 2.2). Shoot length increased as temperature increased for all seed groups at both constant and alternating temperatures. At 20/30°C, all seed groups had longer shoots than at 15/20°C. A similar trend was observed for the constant temperatures whereby shoots were longer at 30°C than at 20°C. Overall, for all temperature regimes, the 15/20°C alternating temperature regime showed the lowest (2.32 cm) while the 20/30°C temperature regime showed the highest (8.70 cm) shoot length. For root length, all seed groups attained their lowest (9.67 – 10.15cm) and highest lengths (15.95 – 19.72cm) at 15/20°C and 20/30°C, respectively (Table 2.2).

No significant differences (P>0.05) were observed for root: shoot ratio among the seed groups. However, highly significant differences (P<0.001) were observed between temperature regimes; the interaction between temperature and seed groups were also significant (Table 2.2). Although the root: shoot was statistically significant, there was no particular trend observed. Root: shoot ratios were lowest at 15/20°C (0.24-0.35cm) with Roundlarge having the lowest ratio (0.24cm) and highest at 20/30°C and 30°C (2.49cm) for Roundlarge and Flatsmall, respectively (Table 2.2).

2.3.3 Fresh and dry mass

Fresh and dry mass showed significant (P<0.05) variations between temperature regimes and among seed groups of SC701 (Table 2.3). However, there were no significant (P>0.05) interaction between temperature and seed groups. At 15/20°C, the fresh masses were lowest (1.14 - 1.42g) than those of 20/30°C (1.94 – 2.45g). Similarly, at 20°C fresh mass were lower (1.41 – 1.79g) than those of 30°C (1.766 – 2.105g). Therefore, at all temperatures (20, 30, 15/20 and 20/30°C), the Roundlarge and Flatsmall attained the highest fresh mass (2.45g) at temperature of 20/30°C and 30°C respectively. In case of dry mass, highest value (0.56g) were found at alternating temperature (15/20°C) for the Roundlarge while the lowest dry mass (0.30g) was found for the Flatsmall at 20°C (Table 2.3).

Table 2. 2: Seedling root and shoot length of four SC701 seed groups after incubation at different temperature regimes.

seed groups	Temperature (°C)	Root length(cm)	Shoot length(cm)	^{z}R:S
	20	12.12abc	5.10bcde	0.42a
Roundlarge	30	15.31abcde	7.33defg	0.49a
	15/20	9.67ab	2.33a	0.24a
	20/30	19.72e	7.93fg	2.49b
	20	11.9abc	4.95abcd	0.42a
Roundsmall	30	17.13cde	7.83efg	0.46a
	15/20	9.32a	3.55abc	0.29a
	20/30	19.32de	8.70g	2.22b
	20	13.45abcde	5.33cdef	2.47b
Flatlarge	30	14.3abcde	7.18defg	0.51a
	15/20	9.78ab	2.50ab	0.26a
	20/30	15.95bcde	6.65defg	0.40
	20	13.27abcd	5.35cdef	0.40a
Flatsmall	30	14.45abcde	6.85defg	2.49b
	15/20	10.15ab	3.55abc	0.35a
	20/30	16.88cde	7.80efg	0.49a
F Pr.		P<0.05	P<0.05	P<0.05
SED		1.96	0.85	0.09
LSD $_{\mathbf{(P=0.05)}}$		3.27	1.42	0.17
CV (%)		14.10	14.90	11.8

^{z}R: S= root: shoot, CV= coefficient of variation

Table 2. 3 Seedling fresh and dry mass of four SC701 varieties after incubation and germination at four different temperature regimes.

Variety	**Temperature (°C)**	**Fresh mass (g)**	**Dry mass (g)**
Roundlarge	20	1.79cd	0.52fg
	30	2.11def	0.48efg
	15/20	1.42abc	0.56g
	20/30	2.45f	0.49efg
Roundsmall	20	1.55bc	0.37abcd
	30	2.03de	0.39abcde
	15/20	1.21ab	0.41bcdef
	20/30	2.07de	0.34abc
Flatlarge	20	1.79cd	0.40abcde
	30	1.77cd	0.32ab
	15/20	1.35ab	0.47defg
	20/30	2.29ef	0.43bcdef
Flatsmall	20	1.79cd	0.30a
	30	2.45f	0.43cdef
	15/20	1.14a	0.33abc
	20/30	1.94de	0.33abc
F Pr.		$P<0.05$	$P<0.05$
SED		0.10	0.03
LSD $_{(P=0.05)}$		0.19	3.27
CV (%)		6.5	8.30

2.2 Discussion

The aim of this study was to determine the interactive effect of seed size and shape on germination characteristics of SC701 maize hybrid under different temperature regimes. Germination is an indication of viability, defined as the property of the seed that allows it to germinate under optimum conditions (Baldwin et al., 2007). Seed germination is an important characteristic and is critical to successful crop establishment in maize (Begna et al., 2001). The results of this study showed that final germination for all the seed groups responded the same way to different temperature regimes since they all attained 100% by the eighth day. In addition, final germination under constant temperature, higher final germination percentage in large seeds may have little advantage compared to smaller seeds due to little differences in germination percentage (Abbasian et al., 2013).

At alternating temperatures (15/20 and 20/30°C), all seed groups behaved in a similar way with regards to germination rate (Table 2.1). The germination rate at 30°C constant was higher than germination rate at 20°C constant among all the seed groups, this could be due to warmer temperature enhancing faster and better germination than cooler temperature. Flatsmall seeds had the highest germination rate at 30°C. This result was consistent with other studies that reported that germination was significantly slower at alternating temperatures than when the temperature was constant (Bircha et al., 2003, Bosci and Kovacs, 1990, Idikut, 2013). High germination rate observed at 30°C constant temperature might be due to rapid hydrolysis and mobilization of seed reserves through higher alpha–amylase activity at higher temperatures.

This study showed that germination rate of round seeds (17.3%) was less than that of flat seeds (45.3%), which could be due to flat seeds having larger surface area for germination than round seeds. Germination rate was also observed to be higher in small than large seeds. Moreno-Martinez et al. (1998) believed that small seeds, in comparison to larger ones, not only germinated faster, but also that their seedlings established more quickly. Popp and Brumm (2003) suggested that the thicker and heavier pericarp of large seeds may explain the slower rate of germination relative to small seed. Shirin et al. (2008) further stated that lipid concentration was higher in small seeds with high germinability than in large seeds. There were no distinct differences between mean germination time of varieties at different temperature regimes.

Germination velocity index (GVI) is a better indicator for germination speed in comparison to germination rate (GR) (Mabhaudhi and Modi, 2010). Results from this study however showed no particular trend in GVI although Flatsmall seeds had the highest GVI at 30°C constant temperature. Results also showed that there were great differences between Roundlarge and Roundsmall seeds for GVI at alternating temperature regimes (15/20 and 20/30°C) but no differences between Roundlarge and Roundsmall seeds in the GVI at 20°C and 30°C constant temperature.

The vigour index for all varieties at four different temperature regimes performed differently. The result showed Flatsmall had the highest vigour index at 20/30°C which could be as a result of its smaller seed size. Therefore, Flatsmall seeds is likely to perform better under field conditions due to its vigour index as supported by other studies (Shirin et al., 2008). While seed vigour index is not a substitute for germination velocity index determined from standard germination, it can, however, complement the standard germination test especially when no trends are observed for GVI as it was for the current study. This is because the seed vigour index is more sensitive than germination test (Abbasian et al., 2013).

During the standard germination test, differences were observed in the seedling root and shoot lengths of flat and round seed groups. However, when the interaction of the seed groups with the temperatures was put into consideration, the germination test showed there were no differences among all varieties (Table 2.2). Results obtained from this experiment were in agreement with studies conducted by Chikoye et al. (2002) and Cathcart and Swanton (2004) in wheat varieties. They found that seedling shoot length increased significantly with increased temperature. According to Tekrony et al. (2005), it is possible to use seedling root :shoot ratio as an index for seedling vigour evaluation. The increasing root: shoot ratios with increasing temperature indicated that shoot mass was lower, but root mass was higher at high temperatures. The present study also found that root: shoot ratio had no significant trend. Similarly, no significant trend of seedling dry and fresh mass of all seed groups under constant and alternating temperatures was observed for small and large seeds at both constant and alternating temperatures. This was possibly due to differences in food reserve of large seeds in comparison to small ones (Shirin et al., 2008).

2.3 Conclusion

The present study showed seed size and shape had a direct and positive effect on germination characteristics of SC701 seeds. This trend was clearer at when seeds were germinated at optimum (30°C) temperatures. Flatsmall seeds germinated faster at constant than alternating temperatures. The results obtained from this study may be useful in selection programmes for different objectives. Where the temperature of a location is known, it is possible to estimate the likelihood of obtaining satisfactory germination of the SC701 hybrid since varying temperature is a major cause of poor crop establishment in many tropical regions. The results can also be used as a tool in germplasm screening programmes for seed germination to distinguish between genotypic and environmental effects. Moreover, knowledge of seed size and shape as well as temperature is a prerequisite to application of any predictive model of crop response to the environment. Outcomes of the study are expected to assist farmers on deciding suitable planting temperature required by SC701 maize hybrid for different planting season of the year. Although the results seem plausible, standard germination test values cannot be directly used to predict field emergence. It will therefore be essential, to compare the results of the present study with field emergence results. Therefore, future studies will investigate performance of hybrid (SC701) seed groups in terms of shape and size at different temperature regimes under a wide range of field conditions.

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CHAPTER THREE

Effect of seed shape, weeding frequencies and planting seasons on growth and development of SC701 maize hybrid under rainfed condition

3.1 Introduction

Maize (*Zea mays* L.) is the third most important crop, after wheat and rice, in the world (Idikut, 2013, McCann, 2005, Rajcan and Swanton, 2001). It is used as human food and animal feed as well as an industrial raw material for products like starch, oil, baby corn and popcorn. As a staple food, it plays an important role in the economy of South Africa. In South Africa approximately 12.5million tons of maize grain are produced annually on approximately 3.3 million ha of land (FAOSTAT, 2012) of which half of the production consists of white maize, for human food consumption (du Plessis, 2003). Currently, there is high demand for maize and it is predicted that by 2050 the demand for maize will double in the developing world (Elmore and Abendroth, 2005). Moreover, maize is predicted to become the crop with the greatest production globally and in the developing world by 2025 (du Toit et al., 2002).

Despite the high demand for maize, there are challenges in increasing production and yield such as such low soil fertility, soil water, erratic rainfall and inadequate weed control. While rainfall still remains the most important limiting factor for increasing maize yield in South Africa (Machethe et al., 2004), weed management, seed selection and duration of the growing period are also factors that consistently affect yield in maize (Kgasago, 2006). In addition to rainfall, maize plants are susceptible to weed competition and yield losses are estimated at 35% to complete crop failure (FAOSTAT, 2012, FAOSTAT, 1999). Maize is very sensitive to weed competition at early stages of growth (Gab-Alla et al., 1985, Gouse et al., 2006). Maize and weeds interfere with growth activities of each other to a varying degree and compete for water, mineral nutrients, and solar radiation and hinder harvest operations (FAOSTAT, 2012, Gouse et al., 2006). Effective and timely weed control will be of great advantage and may assist farmers to control weeds in their maize fields. This will in turn increase maize production and hence help improve productivity of smallholder production systems.

Another important consideration for improving maize productivity may be seed selection especially with regards to seed shape. Maize seed shape varies due to genetics composition and location of kernels on the ear due to the sequential development of the maize ear from the base to the tip. This results in variations in seed from a single ear; round seeds usually come from the base of the ear while flat seeds come from the centre (Graven and Carter, 1990). Seed shape is also dependent on environmental conditions prevailing during crop development and grain filling stage (Mazur and Feranec, 1994). Several studies have considered the relative performance of maize seed shapes and found few differences in growth or grain yield. Grant et al. (1989) compared round and flat seeds of single-cross hybrid maize and found that the effects of seed shape on plant growth and development were minor. Mazur and Feranec (1994) conducted an experiment on the effect of seed size and shape on sprouting of maize seed. They found that seed shape had a significant effect on emergence and yield. Graven and Carter (1990) observed that grain yield among different maize seed shapes was the same.

SC701 is a popular hybrid seed group among small-scale farmers who practice on rain fed agriculture in KwaZulu–Natal, South Africa. It is a high yielding variety with fairly good drought tolerance and hence an optional variety under dryland farming. It has large cob size which is an important selection criteria for farmers who produce green mealies (Corke and Kannenberg, 1989). The variety is usually planted in late spring or early summer when soil temperatures are low (10–11°C) and it normally take between 138 – 150 days after sowing to mature. Few studies have studied growth and yield responses of SC701 to limited soil water availability (Fanadzo, 2007). However, literature describing growth and yield responses of SC701 to weeds is scarce. Moreover, the combined effect of weeding frequency and seed shape on maize yields has not been fully explored. Understanding weeding frequency may help to reduce the demand and competition for labour in smallholder agriculture. In addition, information on planting date selection will also go some way in assisting farmers to make informed decisions. Generally, when farmers plants SC701 maize for green mealies in October/November, harvesting will coincide with a glut in the market resulting in lower prices for the farmer. Late cropping (March/April) and possible harvest during winter when green mealies are in low supply may fetch higher prices for farmers.

Therefore the aim of this study was to estimate the effect of seed shapes and weeding frequency on growth and yield of SC701 planted twice (winter *vs*. summer) within a year in KwaZulu–Natal. It was hypothesized that flat seeds of SC701 will perform better in growth and yield than round seeds under any weeding frequency for any particular planting season.

3.2 Material and Methods

3.2.1 Planting material

Round and flat seeds of SC701 maize hybrid of uniform size were obtained from McDonalds Seed Company, Pietermaritzburg, KwaZulu–Natal.

3.2.2 Site Description

Field experiments were conducted during summer and winter seasons at two locations in KwaZulu–Natal. The first site was the University of KwaZulu-Natal's Ukulinga Research Farm in Pietermaritzburg (29°37'S; 30°16'E; 745 m a.s.l). The second site was at Umbumbulu the Northern part of Pietermaritzburg (29°98S 30°25E, 548 m a.s.l). Ukulinga belongs to the Hinterland Thornveld bio–resource group and is characterised by annual rainfall ranging from 644 – 838 mm and the mean annual temperatures of 18.4°C (Table 3.1). Umbumbulu belongs to the moist coast hinterland and Ngongoni Veld bio–resource group with mean annual rainfall of 800 – 1160 mm. The mean annual temperature at Umbumbulu is 17.9°C and the area experiences light frosts occasionally (Smith, 2006). The experiments at Ukulinga were planted the on 15 November, 2012 (summer) and 4 April, 2013 (winter). Planting at Umbumbulu was done on 22 November, 2012 (summer) and 11 April, 2013 (winter). Ukulinga has a warm subtropical climate with rainfall received mainly during the summer months (November – March).

Table 3. 1: Long-term climatic data (rainfall and temperature) for Ukulinga and Umbumbulu.

Location	Annual	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Ukulinga	**Rainfall (mm)**	59.80	74	83.30	145.00	44.60	94.20	28.20	20.90	4.70	13.75
	Temperature (Max °C)	23.13	26.43	26.82	27.55	25.79	25.17	23.32	22.53	21.26	23.50
	Temperature (Min °C)	14.60	17.00	17.08	16.89	16.19	13.30	11.38	9.53	9.89	9.71
Umbumbulu	**Rainfall (mm)**	165.20	64.70	105.60	84.50	137.40	123.80	32.30	24.00	6.30	5.30
	Temperature (Max. °C)	21.77	25.47	25.45	25.9	24.58	24.20	23.03	21.77	19.68	20.66
	Temperature (Min. °C)	13.95	16.63	16.86	16.56	15.61	13.38	11.34	9.03	9.84	8.76

3.2.3 Site soil characteristics

Soil profiling was done at both locations by digging a 1 m^2, 1 m deep profile pit. The soil profile at Umbumbulu consists of two distinct horizons. The top horizon (A) is a black clay loam soil and the bottom layer (B) is a very dark brown clay loam soil. The soil profile at Ukulinga consist of three distinct horizons, top consist of dark brown (Horizon A), middle had light brown (Horizon B) and bottom consist rocky clay soil (Horizon C) (Fig. 3.1). A composite soil sample to a depth of 10 cm was drawn from each experimental area before sowing during summer and winter season and were analysed for physical and chemical properties and values obtained are furnished in (Table 3.2).

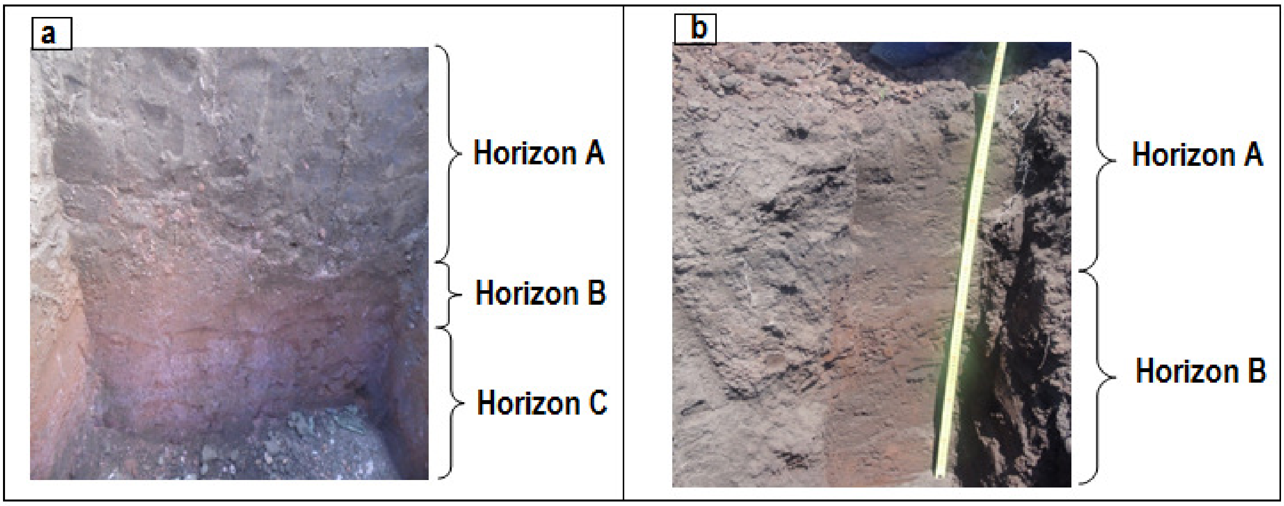

Figure 3. 1: Soil profile at Ukulinga (a) and Umbumbulu Sites (b)

3.2.4 Field layout and experimental design

The experimental design was a factorial experiment arranged in a completely randomised design. There were four factors; location (Ukulinga and Umbumbulu), season (summer and winter) weeding frequency (no weeding, single and double weeding), and shapes (SC701 round and flat) replicated for times. The size of field trial was 255 m^2 and 191.25 m^2 for Ukulinga and Umbumbulu, respectively. Sub-plot size at both sites were 6 m^2 each, planting spacing was 0.5 m x 0.75 m, translating to 25 and 20 plants per plots at Ukulinga and Umbumbulu, respectively. Two seeds per station were sown directly at a depth of 50 mm and later thinned to one seedling per station at 4 weeks after planting (WAP). The weeding frequencies were no weeding (no weed removal), single weeding (weed removal done at 6WAP) and double weeding (weed removal done at 6 and 10WAP, respectively) (Fig 3.2 and Fig 3.3).

Figure 3.2: Weeding frequencies (from left to right: double, single, none) Umbumbulu site.

Figure 3. 3: Weeding frequencies (from left to right: none, single and double weeding) of Ukulinga site.

3.2.5 Data collection

Emergence was counted weekly starting from seven days after planting (DAP), until full emergence. Full emergence was defined as when plants had attained 90% emergence. Plant height was measured from the soil surface to the tip of plant weekly. Leaf number was counted weekly for leaves with at least 50% green leaf area (Mabhaudi and Modi, 2013) starting from crop establishment (90% emergence) until flowering. Days to tasselling (DTT) were counted as number of days from sowing to when 50% of the population had tasselled. Yield components such as biomass, harvest index, number of kernels/row, and number of row/cob, number of ears/plant and seed mass were determined at harvest. At 50% tasseling, stomatal conductance was measured from the abaxial surface during midday (1200–1400 hrs.) using a steady state leaf porometer (Model SC-1, Decagon Devices, USA). Chlorophyll content index was recorded at 50% tasseling at midday on the adaxial surfaces, using the CCM-200 *Plus* chlorophyll content meter (Opti-Sciences, USA). Both stomatal conductance and chlorophyll content index were measured from the ear leaf. Weed counts were made by placing a quadrant (1 m x 1 m) at random locations in plots, repeated four times, in order to obtain a reasonably good estimate of small weeds. Weed densities were calculated as number of weed species divided by total number of weeds within the quadrant.

3.2.6 Crop management

Land preparation was done prior to planting and involved ploughing and disking. At Ukulinga, land preparation also included rotovating. Soil samples were taken from the first top soil (0-10 cm) and submitted for fertility analyses. Based on results of soil fertility analyses, a basal fertiliser, 2:3:2 (22), was applied 8 weeks after planting at a rate of 200 kg ha^{-1} and 350 kg ha^{-1}

during summer planting and 60 kg ha^{-1} and 315 kg ha^{-1} during winter planting season at Ukulinga and Umbumbulu, respectively. Weeding was done using hand hoes based on treatments as described in Section 3.2.4.

3.2.7 Weather and soil water content

Weather data (maximum and minimum temperatures, maximum and minimum relative humidity, reference evapotranspiration and rainfall) for Ukulinga and Umbumbulu for the duration of the study (November 2012 to September 2013) were obtained from the Agricultural Research Council's Institute for Soil, Climate and Water (ARC–ISCW) network of automatic weather stations. Measurements shown are monthly averages compiled from hourly readings. For soil water content, three samples per treatment were taken weekly from the 30 cm profile throughout the duration of the study. Soil samples were weighed to obtain mass of wet soil and thereafter dried at 80°C until they had reached constant mass. Soil water content was then calculated using formulas follows;

Soil water content = [(wet soil – dry soil) /dry soil] x 100 **Eq. 3. 5**

3.3 Data Analysis

Data were analysed using analysis of variance (ANOVA) from GenStat® Version 14 (VSN International, UK). Means were separated using Duncan's Multiple Range Test in GenStat® at the 5% significance level.

3.4 Results

3.4.1 Soil fertility

The soil organic carbon, nitrogen and exchangeable acid were higher at Umbumbulu site than Ukulinga site. However, Ukulinga soil contains higher phosphorus, potassium, calcium, magnesium, total cations, acid saturation, manganese and soil density than Umbumbulu site. There was depletion in soil organic carbon, nitrogen, phosphorus, exchangeable acid manganese, and density from summer to winter season (Table 3.2). However, there was an increase in potassium, calcium, total cations and zinc increase from summer to winter.

Table 3. 2: Soil chemical analysis before summer and winter planting for both sites

Chemical property	**Summer**		**Winter**	
	Umbumbulu	**Ukulinga**	**Umbumbulu**	**Ukulinga**
Organic carbon	5.8%	2.2%	5.1%	2.0%
Nitrogen	0.33%	0.25%	0.31%	0.24%
Phosphorus	2mg/L	27mg/L	5mg/L	18mg/L
Potassium	28mg/L	220mg/L	33mg/L	353mg/L
Calcium	300mg/L	1472mg/L	365mg/L	2004mg/L
Magnesium	220mg/L	402mg/L	109mg/L	811mg/L
Exchangeable acid	4.2Cmol/L	0.22Cmol/L	3.38Cmol/L	0.09Cmol/L
Total cations	6.20Cmol/L	11.44Cmol/L	6.18Cmol	17.67Cmol/L
Acid saturation	98%	2.0%	55%	1.0%
Zinc	1.8mg/L	2.6mg/L	3.9mg/L	4.7mg/L
Copper	2.1mg/L	8.7mg/L	4.4mg/L	20.1mg/L
Manganese	5mg/L	40mg/L	6mg/L	30mg/L
Clay	58%	32%	59%	36%
Density	0.99%	1.17g/mL	0.85%	1.08g/mL

3.4.2 Weather data and soil water content

The respective average minimum (Tmin) and maximum (Tmax) temperatures for the summer and winter trials at Ukulinga site were 16.35°C, 10.76°C, 23.16°C and 25.94°C while for Umbumbulu they were 15.92°C, 13.44°C, 23.37°C and 24.63°C, respectively. The minimum soil temperature for maize germination is 10-11°C and the optimum temperature for vegetative growth is 30°C. When the crop was planted during the summer season minimum temperatures were above the base temperature (10°C), therefore providing favourable conditions for successful germination and emergence. The total rainfall received during the summer and winter growing seasons at Ukulinga were 406.7 mm, 162 mm and at Umbumbulu 557.4 mm and 191.7 mm, respectively (Figure 3.4). At the beginning of summer planting season, rainfall and temperatures were relatively high; thereafter, rainfall and temperature decreased with the onset of winter. It is important to note that as winter was setting in, there were days when temperatures were below the base temperature (10°C) for maize growth (Figure 3.3).

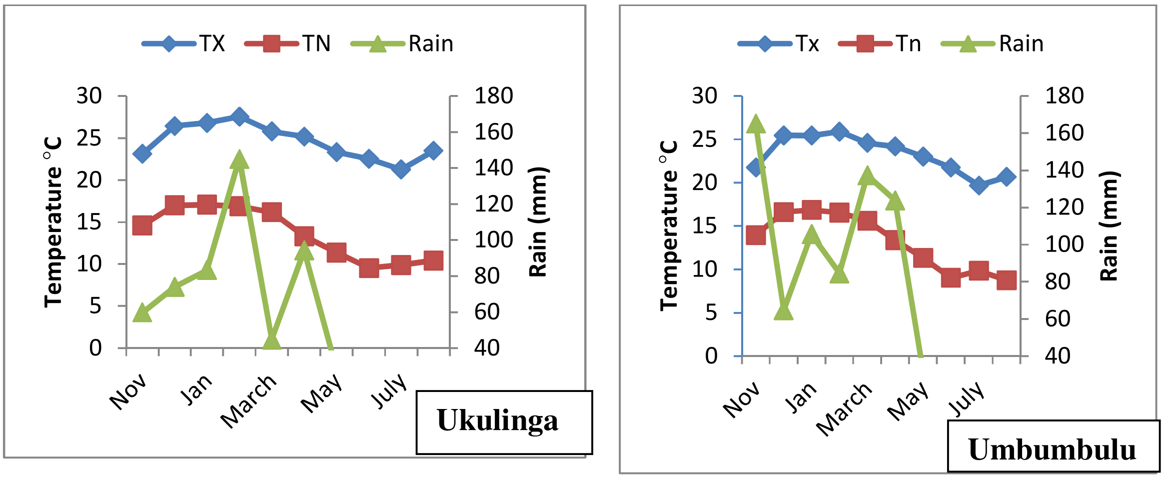

Figure 3. 4: Weather conditions for Ukulinga and Umbumbulu during the growing season of SC701 maize.

During the summer season, there were highly significant differences (P<0.001) in soil water content (SWC) between Umbumbulu and Ukulinga. Also, significant differences (P<0.05) were observed four weeks after planting (WAP). The SWC among weeding frequencies showed significant variation (P<0.05). The interaction between weeding frequencies and varieties was highly significant (P<0.001). Umbumbulu had higher SWC compared with Ukulinga during the summer trials (Figure 3.5). The SWC increased from 1WAP to 3 WAP, at 4WAP decreasing trend were observed till 10WAP later increased from 14WAP to 16 WAP at Umbumbulu site. While at Ukulinga site, increased in SWC were observed from 2WAP to 4WAP then decreased from 5WAP to 12 WAP and later picked up from 13WAP to 16WAP. Double weeding had the highest SWC at both sites throughout WAP. Flat shape interaction with all weeding frequencies had the highest SWC among the weeding frequencies. The unweeded plots had the lowest SWC among the weeding frequencies at Ukulinga and Umbumbulu.

During winter planting season, the two planting sites showed a highly significant (P<0.001) differences in SWC. Also, highly significant differences were observed among WAP but there were no significant interaction (P>0.05) among weeding frequencies and shapes. Increase in SWC was observed from 3WAP to 5WAP, decreased 6WAP later picked up at 11WAP finally decreased from 13WAP till 21WAP. No weeding treatment showed decreasing trend throughout WAP. There was no distinct trend between SWC in single and double weeding throughout WAP.

Flat combination with all weeding frequencies have higher SWC than round combination with weeding frequencies expect at no weeding throughout WAP and for both sites.

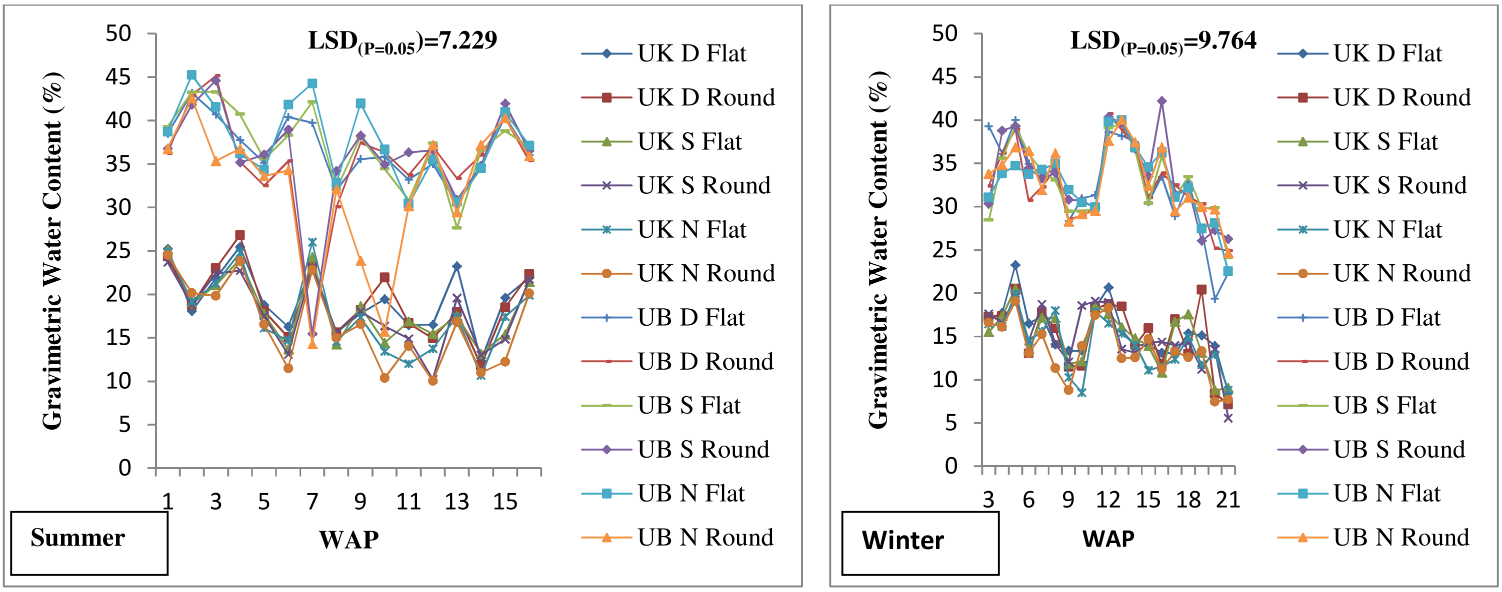

Figure 3. 5: Soil water content measured during summer and winter planting season for Ukulinga (UK) and Umbumbulu (UB) site; D = Double Weeding, S = Single Weeding, N = No weeding

3.4.3 Weed composition

There were 11 prevalent weed species occurring at Ukulinga and 18 weed species at Umbumbulu (Table 3.3 and 3.4). During summer planting season, the dominant weeds at Ukulinga were *Panicum maxmum, Bidens pilosa*, *Cynodon dactylon,* and *Cirsium vulgare* while *Zebrina pendula*, *Bidens pilosa, Ageratum conyzoides*, *Sida rhombifolia*, *Cynodon dactylon*, *Cyperus esculentus*, *Solanum nigrum,* and *Richardia brasiliensis* were dominant at Umbumbulu.

During winter planting season, dominant weeds at Ukulinga were *Xanthium strumarium, Solanum nigrum* and *Portulaca oleracea* while at Umbumbulu *Bidens pilosa, Sida rhombifolia, Ageratum conyzoides* were prevalent. Annual broadleaf were more dominant than grass weeds at both sites.

Table 3. 3: **Weed classification and density of none weeded SC701 maize during summer and winter growing season at Ukulinga site.**

Weed Species	Weed classification	Weed frequency	Weed density m^2	Weed frequency	Weed density m^2
		Summer		**Winter**	
Panicum maxmum	Grass	38	54%		
Bidens pilosa	Broadleaf	10	14.3%	1	1.1%
Xanthium strumarium	Broadleaf			11	12.4%
Ipomoea hederacea	Broadleaf	4	5.7%	2	2.3%
Solanum nigrum	Broadleaf			37	63.8%
Cynodon dactylon	Grass	10	14.3%		
Portulaca oleracea	Broadleaf			5	5.6%
Cyperus esculentus	Sedges			1	1.1%
Cirsium vulgare	Broadleaf	6	8.6%		
Ageratum condozoiyes	Grass			1	1.1%
Seteria viridis	Grass	2	2.9%		

Table 3. 4: Weed classification and their relative density of no weeded SC701 maize during summer and winter growing season at Umbumbulu site

Weed Species	Weed classification	Season	Weed density m^2	Season	Weed density m^2
		Summer		**Winter**	
Zebrina pendula	Broadleaf	12	8.2%	2	14.3%
Axonopus compressus	Grass	6	4.1%		
Bidens pilosa	Broadleaf	10	6.8%	4	28.6%
Dactyloctenium aegyptium	Grass	3	2.0%		
Euphorbia heterophylla	Broadleaf	1	0.7%		
Ipomoea hederacea	Broadleaf	4	2.7%	1	7.1%
Ageratum conyzoides	Grass	16	10.8%	2	14.3%
Sida rhombifolia	Broadleaf	9	6.1%	3	21.4%
Cynodon dactlon	Grass	10	6.8%		
Acanthospermum hispidum	Broadleaf	4	2.7%		
Cyperus esculentus	Sedge	33	22.5%		
Cirsium vulgare	Broadleaf	6	4.1%		
Panicum maxmum	Grass			1	7.1%
Solanum nigrum	Broadleaf	12	8.2%		
Abutilon theophrasti	Broadleaf	4	2.7%	1	7.1%
Panium maxum	Grass	14	9.5%		
Digitaria ischaemum	Grass	3	2.04		

3.4.4 Emergence and growth

Emergence of SC701 maize during summer and winter seasons varied significantly ($P<0.001$) as well as across sites. Emergence during summer was 60% higher than during winter season. Umbumbulu had 10.8% higher emergence than Ukulinga. (Figure 3.6). Although no differences in mean values, flat shape emerged better (1.4%) than the round shape. In addition, the flat showed better vigour than the round by emerging better in the no weeding and single weeding plots.

Results showed that emergence was faster during summer than in winter season. During summer, both shapes had similar emergences at both sites, reaching 90% emergence between 0–7 days after planting (DAP) and reaching maximum emergence at 14 DAP. There were little differences in maize emergence under the weeding frequencies plots during winter season and the same was observed during summer planting season (Figure 3.6).

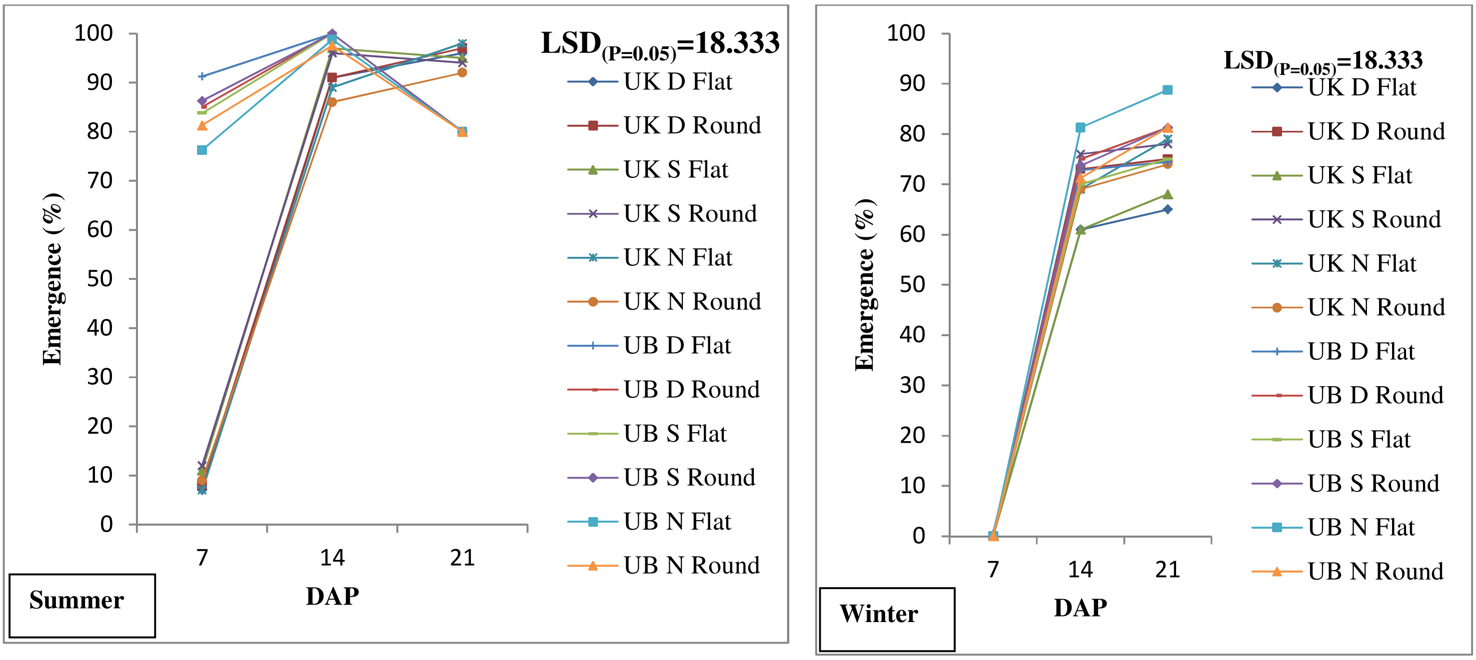

Figure 3. 6: Emergence in percentage observed during summer and winter planting season for Ukulinga (UK) and Umbumbulu (UB) site; D= Double Weeding, S = Single Weeding, N = No weeding.

Measurement of plant height and leaf number started 2WAP during summer and 3 WAP during winter season when plants had fully established. In respect to plant height, there were significant differences (P<0.001) between summer and winter planting seasons, and at both sites. Also highly significant differences (P<0.001) were observed among weeding frequencies and throughout WAP. There were highly significant interactions between weeding frequencies. However no significant differences were observed in plant height between the shapes.

During summer season, there were no distinct trends in plant height between the two seed shapes. Plant height at Umbumbulu site were higher (94.10 cm) compared with plant height at Ukulinga (91.71 cm), 2WAP, flat variety had the highest plant height in all the weeding frequencies at Ukulinga site. Three WAP, there were no trend in interaction of shapes and weeding frequencies at both sites (Figure 3.7). Increasing trend in plant height was observed from 3WAP till 14WAP. Double weeding (weed removal done twice) had the highest plant height (95.77 cm) at 6 WAP followed by single (weed removal done once) (92.74 cm) and no weeding (no weed removal) (90.22 cm) respectively at both sites. At both sites there were no distinct trends in interaction between shapes and weeding frequencies with regards to plant height (Figure 3.7).

During winter planting season, there were highly significant differences ($P<0.001$) in plant height at both sites and among the weeding frequencies. Plant height at Ukulinga (25.38cm) was higher than Umbumbulu (10.37cm) at 3WAP. There were no trends in weeding frequencies and shapes interaction with regards to plant height at both sites. Decrease in plant height was however observed at Ukulinga site at 12, 17 and 18WAP for all weeding frequencies in both shapes. Round had higher plant height than flat for all the weeding frequencies at Ukulinga site while flat has higher plant height than round at Umbumbulu site. It was also observed from both sites that a decreasing trend of plant height started at 17 WAP for all shapes.

Over-all, plant height decreased significantly from summer season to winter season. A comparison of shapes at both seasons and sites showed that, (although no statistically significant differences) round (55.79 cm) performed better than flat (54.99 cm), double and single weeding performed better than no weeding in regards to plant height (Figure 3.7).There were no statistically differences in plant height between single and double weeding at both seasons.

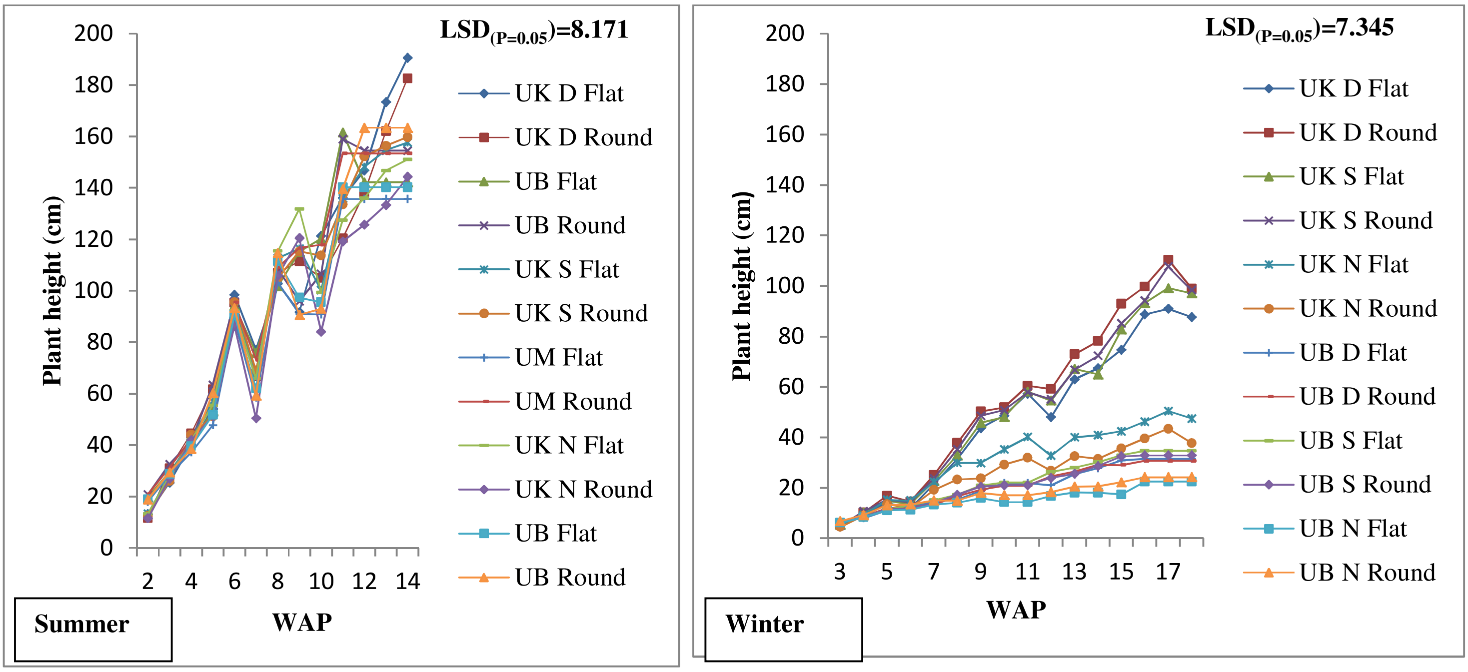

Figure 3. 7: Plant Height measured during summer and winter planting season for Ukulinga (UK) and Umbumbulu (UB) site; D = Double Weeding, S = Single Weeding, N = No weeding

There were highly significant differences in leaf number (P<0.001) between summer and winter planting season, at both sites and between shapes throughout the planting periods (WAP) (Figure 3.8). Also highly significant differences (P<0.001) were observed in leaf number among the weeding frequencies and highly significant difference P<0.001) occurs in the interactions between shapes and weeding frequencies.

During summer, Ukulinga site (9.00) had higher leaf number than Umbumbulu site (8.00) and differences in the leaf number started to be distinct at 5WAP during summer growing period with an increasing trend from double, single and no weeding across WAP respectively, while during winter, with regards to the shapes there were no trend in their leaf numbers. Differences started to be distinct at 7 WAP with a decreasing trend from double weeding, single weeding and no weeding respectively across weeks after planting (Figure 3.8).

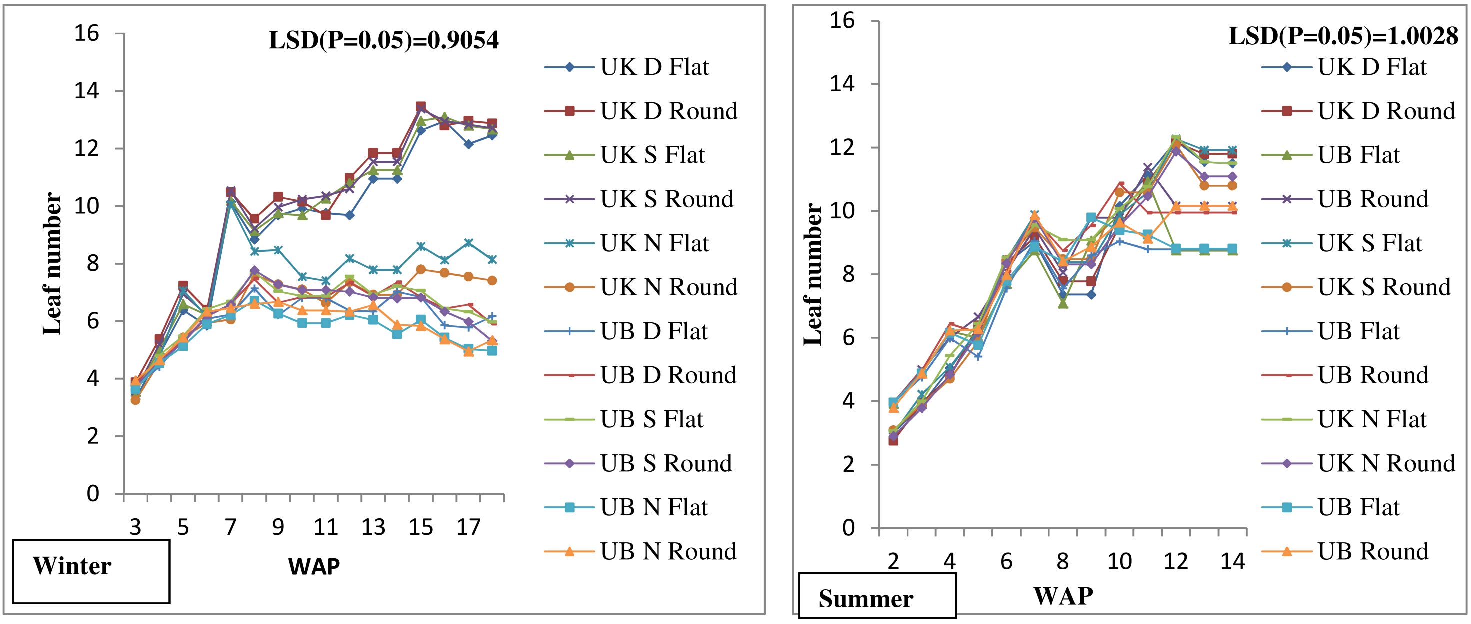

Figure 3. 8: Leaf number measured during summer and winter planting season for Ukulinga (UK) and Umbumbulu (UB) site; D= Double Weeding, S = Single Weeding, N = No weeding

3.4.5 Days to tasseling (DTT)

There were no significant differences in days to tasseling (DTT) between shapes and its interaction with weeding frequencies. However, DTT were significantly affected by different planting seasons at both sites. There were highly significant differences (P<0.001) in DTT at Ukulinga and Umbumbulu. Ukulinga site reached DTT faster than Umbumbulu by 14.99% during summer. Round was 1.4% faster than flat. No weeding (91DAP) had the longest time to DTT followed by single (80.50DAP) and double weeding (77DAP).The trend of weeding frequencies interaction with variety observed were double weeding round and flat<single weeding flat<single weeding round<single weeding flat< no weeding round and flat for both sites during summer season (Figure 3.9). While during winter season, there were significant differences in DTT among the weeding frequencies. Double weeding (120.50DAP) reached tasseling stage fastest, followed by single (124.25DAP) and no weeding (134DAP), flat was 2.09% faster in DTT than round. Double weeding flat< double weeding round<single weeding flat <single weeding round <no weeding flat and no weeding round. Weeding affected DTT during both season and at both sites

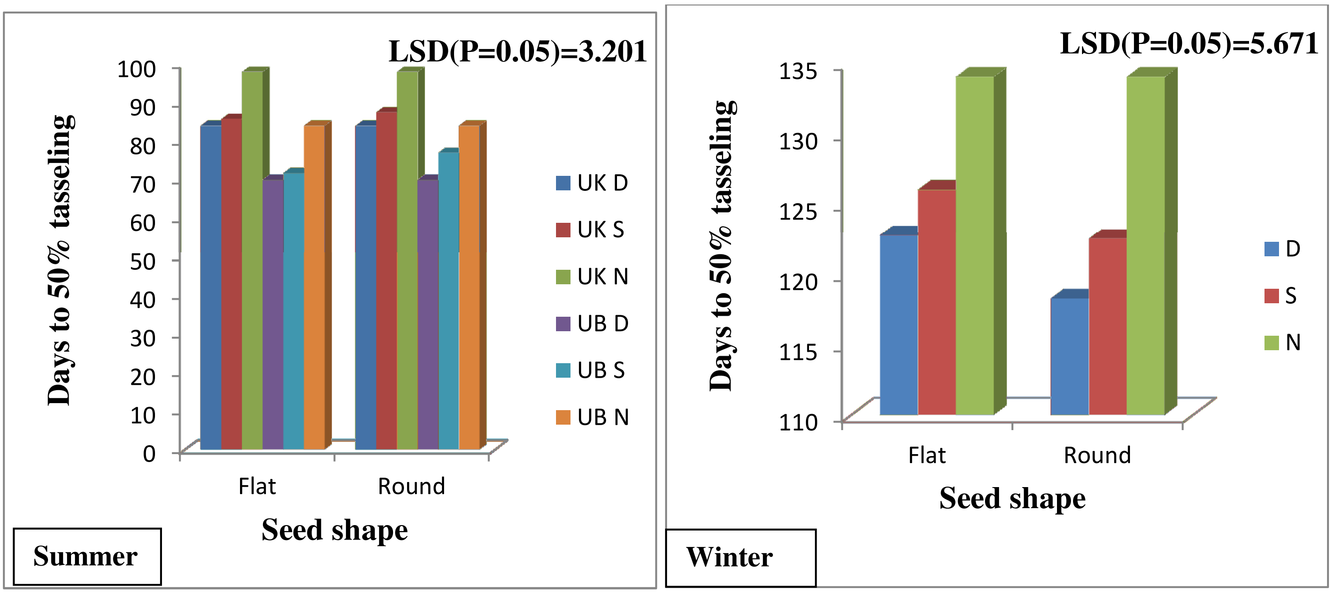

Figure 3. 9: Days to tasseling (DTT) for both sites during summer and winter planting at Ukulinga. Seasons for Ukulinga (UK) and Umbumbulu (UB) site; D = Double Weeding, S = Single Weeding, N = No weeding

3.4.6 Crop physiology

There were high significant differences ($P<0.001$) between summer and winter planting seasons with regards to stomatal conductance, with summer season having 22.62% higher stomatal conductance (SC) than winter season. Also, high significant differences ($P<0.001$) were observed between planting sites, with Umbumbulu site having 6.42% and 40.77% higher than Ukulinga site during summer and winter season respectively. During summer season, there were highly significant differences ($P<0.001$) in SC at both sites and throughout weeks after tasseling (WAT) but, no significant differences ($P>0.05$) in stomatal conductance among the weeding frequencies. No significant interactions ($P>0.05$) were observed in stomatal conductance between shapes, and weeding frequencies (Figure 3.10). Increasing trends in SC was observed from 1WAT till 5WAT at both sites. The highest stomatal conductance was obtained at single weeding (73.00 mmol m^{-2} m^{-1}) followed by double weeding (72.40 mmol m^{-2} m^{-1}) and no weeding (40.20 mmol m^{-2} m^{-1}). Moreover, among the weeding frequencies interaction with shapes, double weeding round had the highest SC followed by single weeding round finally no weeding flat shape throughout weeks after tasseling except at 1WAT where double weeding flat had higher SC than double weeding round.

During winter planting season, there were highly significant differences (P<0.001 between SC in plant from Umbumbulu and Ukulinga. Also, highly significant differences were also observed among the weeding frequencies and throughout weeks after tasseling. However, there were no significant differences (P>0.05) in SC between varieties, also in varieties and weeding frequencies interaction. Decreasing trends in SC was observed from 1WAT till 4WAT at both sites. Flat variety was 2.27% higher than round shapes. Single weeding (53.80 mmol m^{-2} m^{-1}) followed double weeding (53.70 mmol m^{-2} m^{-1}) and no weeding (36.00 mmol m^{-2} m^{-1}). There were decreasing trend from double weeding flat >double weeding round >single weeding flat >single weeding round >no weeding flat >no weeding round. During winter season SC decreased throughout week after tasseling at both sites.

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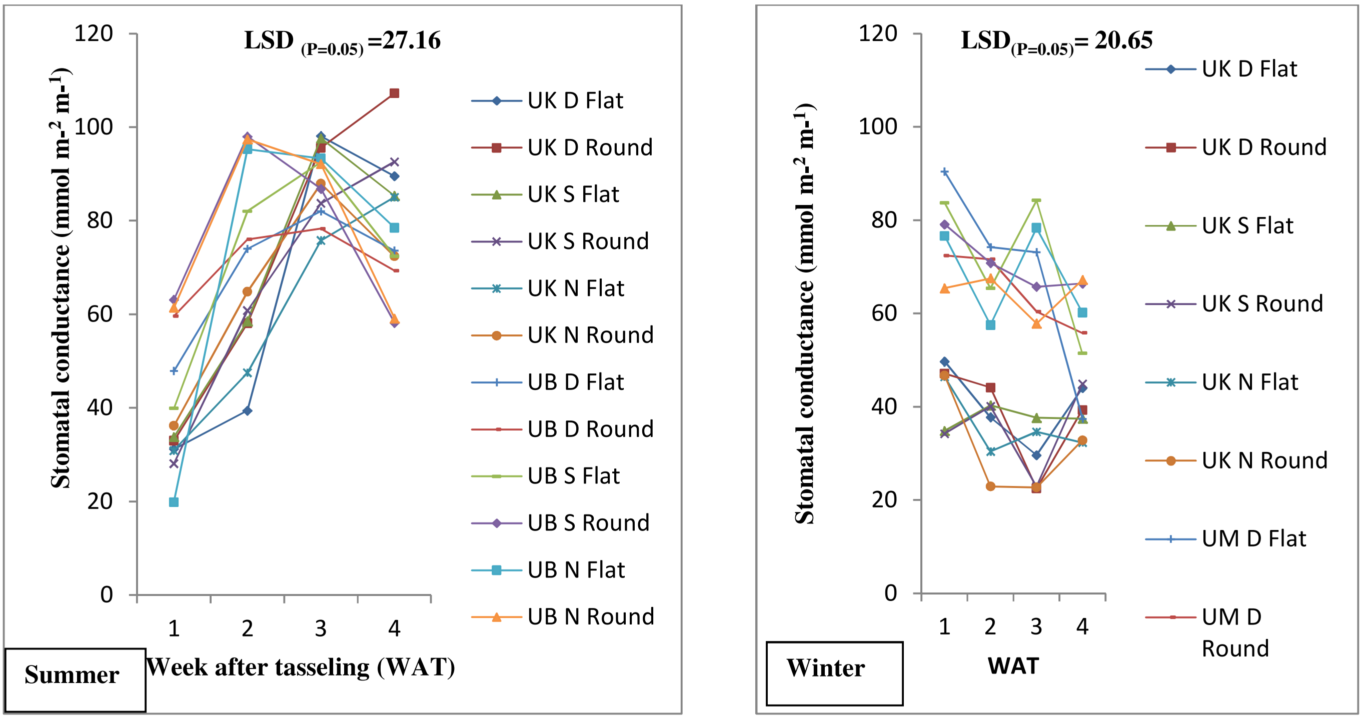

Figure 3. 10: Interactive effects of weeding competition and shape of SC701 maize on its stomatance conductance measured at reproductative stage for both sites during summer and winter planting seasons for Ukulinga (UK) and Umbumbulu (UB) site; D = Double Weeding, S = Single Weeding, N = No weeding

Results of chlorophyll content index (CCI) during winter season showed highly significant differences (P<0.001) between Umbumbulu and Ukulinga sites. Also, significant differences were observed among weeding frequencies and its interaction with weeks after tasseling (WAT).However, there were no significant interactions (P>0.05) in CCI between shapes and weeding frequencies. CCI was higher at Umbumbulu site by 38.85% compared with Ukulinga site, CCI in double weeding (12.01) was the highest followed by single weeding (11.42) and no weeding(8.97) while double weeding was 4.91% higher than single weeding and 25.3% higher than no weeding. Round variety was 3.46% higher compared with flat shapes. Chlorophyll content index decreased with time from 1WAT and the same trend was obtained at Umbumbulu site except at 3 WAT. Double weeding round >double weeding flat>single weeding round>single weeding flat>no weeding round >no weeding flat at Ukulinga site but no trend were observed for CCI at Umbumbulu site. CCI increased from 1WAT to 2WAT and decrease from 3WAT to 4WAT at both sites (Figure 3.11). Results of CCI during summer season showed highly significant differences (P<0.001) between planting sites. Also, highly significant differences (P<0.001) where observed in the CCI throughout week after tasseling (WAT). In addition, highly significant differences (P<0.001) occurred among weeding frequencies. However, there were no statistically significant (P>0.05) in CCI between shapes, also, no significant interaction (P>0.05) were observed in CCI between varieties and weeding frequencies. Chlorophyll content index had an increasing trend throughout weeks after planting. Double weeding (16.98) had the highest followed by single weeding (16.96) and no weeding (14.36).The CCI of maize plant at Umbumbulu site was 45.19% higher than those at Ukulinga site and CCI of round shapes was 7.14% higher than flat shapes at Umbumbulu and flat shapes was 5.93% higher than round at Ukulinga site.

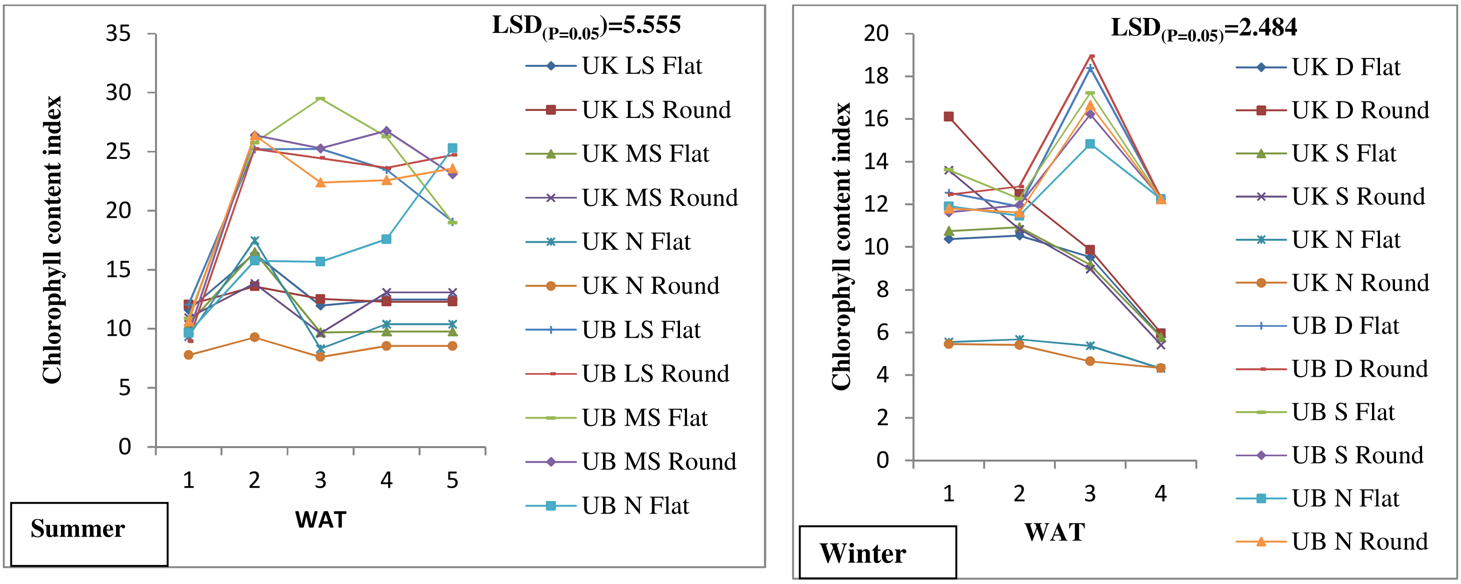

Figure 3. 11: Interactive effects of weeding competition and shape of SC701 maize on its chlorophyl content for both sites during summer and winter planting seasons for Ukulinga (UK) and Umbumbulu (UB) site; D= Double Weeding, S = Single Weeding, N = No weeding

3.4.7 Yield components

During summer planting season, there were significant differences (P<0.05) among weeding frequencies in regards to harvest index but interaction between weeding frequencies and shapes showed no significant differences (P>0.05), Harvest index at Umbumbulu site performed better by 10.34% compared with Ukulinga site. The Harvest index among weeding frequencies at both sites had an increasing trend from double (27.16) to single (26.05) and no weeding (22.22) where double weeding was 18.2% higher than no weeding and 4.08% higher than single weeding. At Umbumbulu site, Round variety performed better than flat by 4.4% and flat performed better than Round by 1.7% at Ukulinga site (Table 3.5). For winter planting season at Ukulinga site, significant differences were obtained among weeding frequencies but no significant differences were obtained in shapes, and the interaction between weeding frequencies and shapes in regards to harvest index. There was increasing trend in harvest index from no weeding (30.00) to single weeding (37.90) and double (45.90) weeding. Flat shape was 3.63% higher than round shapes. Double weeding flat shapes >double weeding round>single weeding flat>single round>no weeding flat>no weeding round shapes (Table 3.6). There were no cobs harvested at

Umbumbulu site therefore no values were obtained for harvest index during winter planting season.

During summer there were significant differences (P<0.05) in total biomass obtained from Ukulinga and Umbumbulu sites. Also, highly significant differences (P<0.001) were observed among the weeding frequencies but there were no significant differences between shapes and its interaction with weed frequencies. Umbumbulu site is 17% higher in total biomass compared with Ukulinga site. Single weeding had the highest followed by double weeding and no weeding. Single was 1.58% higher than double weeding and 2.9% higher compared with no weeding. The result of total biomass during winter season showed highly significant differences (P<0.001) among weeding frequencies but there were no significant differences (P>0.05) between shapes. Also, no significant differences were observed among weeding frequencies and shapes interactions. Umbumbulu site performed better compared with Ukulinga site by 1.56%.decreasing trend was observed from double, single and no weeding. Double weeding was 3.9% higher than single and 37.8% higher than no weeding. Round performed better than flat by 2.92.

However, no distinct trends in total biomass were observed in the interaction between weeding frequencies and shapes, it ranged from double weeding round variety (126g) to no weeding flat (72.2g) while during summer, the interaction of round variety with all weeding frequencies had higher total biomass than the interaction of flat shapes with all the weeding frequencies at Umbumbulu site while the interaction of flat shapes with all the weeding frequencies had higher total biomass than the interaction of flat shapes with all the weeding frequencies at Umbumbulu

During summer season, there were highly significant differences (P<0.001) in number of kernel per row of maize planted at Ukulinga and Umbumbulu site. Also, significant differences (P<0.05) in number of kernel per row were observed among the weeding frequencies and highly significant differences (P<0.001) were observed in number of kernel per row among the interaction of weeding frequencies with shapes. However, no significant differences were observed between shapes. The number of kernel/row of cobs harvested from Umbumbulu site was 60.89% higher than those harvested from Ukulinga site during summer season (Table 3.6). The kernel per row in Flat variety was higher by 4.67% than round shapes number of kernel per row in double and single weeding compared with no weeding. Double weeding has higher number of kernel per row compared to single by 2.85% and 27.8% compared to no weeding (Table 3.5). The number of kernel/row at Umbumbulu site was higher compared with Ukulinga site by 60.89%. Decreasing trend was observed from double (27.81) to single (26.68) and no weeding (18.91).The number of kernel per row in double weeding flat shape >double weeding round>single weeding round>single weeding flat>no weeding flat>no weeding round. While during winter season, significant differences were observed among the weeding frequencies but there were no significant differences between varieties, also in the varieties interaction with weeding frequencies at Ukulinga site. Flat shape was 1.89% higher in number of kernel /row than round variety. Similar trend observed in shapes interaction with weeding frequencies during summer were also observed during winter season with double flat having the highest number of kernel per row (Table3.7). There was no cob harvested at Umbumbulu site during winter season.

During winter season, there were no significant differences ($P>0.05$) in number of row /cob between shapes and among weeding frequencies at (Table 3.6). However, significant differences ($P<0.05$) were observed for the interaction between variety and weeding frequencies. No distinct trend were observed in the varieties interaction with weeding frequencies, Single flat had the highest row /cob and the lowest was found in no weeding flat variety. There was no result for number of row per cob at Umbumbulu site.

There were significant differences ($P<0.05$) in the cob mass at Ukulinga and Umbumbulu site with Umbumbulu having 23.25% higher cob mass than Ukulinga (Figure 3.12 -3.14). Differences were observed among the weeding frequencies, with double weeding having the highest cob mass followed by single weeding and no weeding had the lowest at both sites. There were no distinct trend of the cob mass in varieties interaction with weeding frequencies at both sites during summer planting season, double weeding round variety had the highest cob mass>double weeding flat>single weeding flat>single round>no weeding flat>no weeding round. During winter season at Ukulinga site, significant differences ($P<0.05$) in cob mass were observed among the weeding frequencies but no significant differences ($P>0.05$) between varieties and its interaction with weeding frequencies (Figure 3.14). Double weeding had the highest (119g) followed by single (101.2g) and no weeding (53.2g) has the lowest cob mass. The distinct trends of the cob mass in shapes interaction with weeding frequencies observed were double weeding flat shape >double round>single flat>single round>no weeding flat>no weeding round.

There were significant differences ($P<0.05$) in cob/plant among the weeding frequencies but no significant differences ($P>0.05$) between shape and its interaction with weeding frequencies. There was no trend in the cob /stand among shapes interaction with weeding frequencies.

Figure 3. 12: Harvested cobs during summer season in response to weeding at Ukulinga. From left to right: No weeding; Single weeding; Double weeding.

Figure 3. 13: Harvested cobs during summer season at Umbumbulu. From left to right: No weeding; Single weeding; Double weeding.

Figure 3. 14: Harvested cobs during winter season at Ukulinga. From left to right: No weeding; Single weeding; Double weeding.

Table 3. 5: Interactive effect of weeding competition and shapes on Yield component of SC701 variety planted at Ukulinga and Umbumbulu sites during summer season.

Site	Variety	Weed Frequency	TB (g)	HI	CN/P	RN/C (g)	KN/R (g)	CM (g)
Ukulinga	Round	No weeding	166.8a	19.77a	1.083a	10.17a	19.51bcd	72.7a
	Flat	No weeding	193.2ab	19.33a	1.042a	10.50a	18.31abc	93.2ab
	Round	Single weeding	359.7abc	23.31ab	1.250a	11.25a	27.20de	137.4abc
	Flat	Single weeding	366.3abc	25.64ab	1.042a	10.46a	26.15cde	150.1abc
	Round	Double weeding	382.3bc	27.62ab	1.000a	11.09a	28.44e	195.3bc
	Flat	Double weeding	338.0bc	26.95ab	1.083a	11.26a	27.18de	158.5abc
Umbumbulu	Round	No weeding	297.5abc	24.88ab	1.083a	10.77a	19.92ab	130.3abc
	Flat	No weeding	268.0abc	2490ab	1.042a	10.68a	21.15a	130.2abc
	Round	Single weeding	458.1c	19.16b	1.167a	11.80ab	32.81c	240.0c
	Flat	Single weeding	346.7abc	26.07ab	1.083a	11.45ab	28.52bc	159.6abc
	Round	Double weeding	419.0c	27.30ab	1.083a	11.60ab	31.40bc	203.7bc
	Flat	Double weeding	399.3bc	26.75ab	1.125a	11.92ab	31.73bc	187.3a
F.Pr			P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05
CV (%)			26.6	12.9	12.9	23.6	18.80	30.1
S.E			79	2.69	0.12	3.75	2.68	46.58
LSD			137.4	4.662	0.20	6.502	6.6	67.01

TB = Total Biomass, HI = Harvest Index, CN = Cob Number, RN = Row Number, C = Cob, KN = Kernel Number, R = Row, CM = Cob Mass

Table 3. 6: Interactive effect of weeding competition and shapes on Yield component of SC701 variety planted at Ukulinga and Umbumbulu sites during winter season.

Site	Variety	Weed Frequency	TB (g)	HI	CN/P	RN/C (g)	KN/R (g)	CM (g)
Ukulinga	Round	No weeding	31.60a	37.00a	0.00	12.57a	18.16bc	52.6a
	Flat	No weeding	46.40 ab	39.00a	0.00	12.44a	17.68b	153.9a
	Round	Single weeding	126.60bc	35.00a	1.04a	12.08a	25.08cd	100.5ab
	Flat	Single weeding	142.90c	25.00a	1.00a	13.25a	25.75d	101.9ab
	Round	Double weeding	148.30c	40.00a	1.04a	12.95a	26.81d	119.4b
	Flat	Double weeding	106.40abc	52.00a	1.00a	11.50a	27.03d	118.5b
Umbumbulu	Round	No weeding	116.30bc					
	Flat	No weeding	97.90abc					
	Round	Single weeding	89.40abc					
	Flat	Single weeding	92.80abc					
	Round	Double weeding	103.80abc					
	Flat	Double weeding	111.70abc					
F.Pr			P<0.05	P<0.05	ns	P<0.05	P<0.05	P<0.05
CV (%)			30.80		26.10	7.00	19.30	24.1
S.E			31.13	0.00	0.0933	0.871	4.58	21.97
LSD			44.84	0.00	0.13	1.42	7.47	35.82

TB = Total Biomass, HI = Harvest Index, CN = Cob Number, RN = Row Number, P = Plant, KN = Kernel Number, R = Row, CM = Cob Mass, ns= no significant difference

3.5 Discussion

The aim of this study was to evaluate the effect of shape and weeding on green mealies growth and grain Yield of SC701 at two sites during summer and winter planting seasons under rainfed condition. Also to monitor effect of weeding on SC701 physiology development especially during its reproductive stages through stomatal conductance and chlorophyll content index while monitoring soil water content in order to redouble it with growth responses. In addition, a secondary objective was to determine maize yield under rainfed condition. Maize production is usually faced with deficit or insufficient soil water due to unevenness of rainfall distribution which plays an important role in determining emergence and seedling development

(Aboutalebian et al., 2012). During adverse and harsh growing conditions like low soil temperature and fertility, limited water availability and hot dry conditions farmer primary target still remain on stable production. Therefore, planting seasons are very important in maize production. Maize produces good yields when planted in the summer season, especially after good rains. In this study we evaluated the possibility of growing SC701 during winter season and compared with conventional summer growing.

It is worthy to note that during the course of this study, the total rainfall received during summer planting season at Ukulinga and Umbumbulu sites were 406mm and 557.4mm respectively while the total rainfall received during winter season were 191.7mm and 148mm. This implies that during winter planting, the total rainfall received were relatively lower than the minimum rainfall requirements for maize production in Southern Africa which are estimated to be about 500 mm spread over the planting season (Department of Agriculture 2008). This rainfall amount influenced the growing environment and hence the final emergence as evidenced by the high differences between two seasons and as discussed below.

There was rapid usage of the organic carbon and macronutrients by maize crop and weeds during summer except the potassium which had slow mobilization, these cause lowering of soil fertility during winter planting season contributed to reduce yield.

Higher soil water content occurred at Umbumbulu site than Ukulinga site during summer but had lower soil water content than Ukulinga site during winter season which may be attributed to higher rainfall received at the site during summer at Umbumbulu than at Ukulinga site and rate of evapotranspiration higher at Ukulinga site. The no weeding plots (no weed removal) had the lowest soil water content at both sites which could be due to weed competition for water and soil nutrients because weeds transpire more water than crops and it can remove moisture from deeper depth of soil than crops (Ali et al., 2011, Silwana and Lucas, 2002). The results were in agreement with (Zimdahl, 1999) and (Dalley et al., 2006) that weed infestation and its duration with crops reduced soil moisture. There were no differences in soil water content for single and double weeding. Also no trends in soil water content between varieties were observed.

The weed species decreased from summer to winter season at both sites due to low soil temperature. Annual broadleaf weeds infestations were higher than grass weed infestation because grasses were not actively growing.

Rapid and uniform field emergence and good seedling establishment is very important in achieving high yield in maize production. There were differences in emergence between sites during winter and summer may be partly attributed to inadequate moisture availability during winter season compared to summer season. Few differences in emergence were observed in varieties planted in both seasons due the varieties were genetically identical. Although, flat variety had higher emergences than round variety (no significant differences) during summer season which was in agreement with Graven and Carter (1990) that reported decrease in percentage emergence of small round maize seed. Emergence during summer was higher than emergence during winter which was in agreement with (Tekrony et al., 2005). There were little differences in emergence among weeding frequencies, the daily emergence was fast during 7-14 DAP, reaching a maximum at 21 DAP during summer season at both sites, but slower during winter which start (14DAP) reaching a maximum (21DAP) due to low soil temperature and insufficient soil water.

Usually, it takes 7 to 14 days under favourable temperatures (15-18°C) for maize to emerge, but under lower temperatures, it can take up to 21 DAP as observed in this experiment which was in agreement with (Kırtok, 1998). According to Kırtok (1998) at temperature lower than 10ºC, it will take longer time for maize to emerge.

leaf number performed well in the beginning of planting for both summer and winter season, the decline in number of leaves per plant started at 5WAP and 7WAP particularly at no weeding for summer and winter season respectively. This could be attributed to leaf senescence which could be induced by different factors including weed competition caused by lack or insufficient soil nutrients and soil moisture (Colomb et al., 2000). Low leaf number per plant in no weeding plots could be due to competition between high population of weeds and maize plants and for light, nutrients, place, water, and other environmental factors which are required for increasing leaf number. During winter season no weeding plots, leaves senescence occurs faster as weed competition with maize to capture resources become more severe i.e. at a higher weed density. Plant leaf senescence is induced by shading (Vos and Van der Putten, 2001) which adversely affected the photosynthetic rate.

Plant height contributes greatly to maize grain yield because taller plants get more sunlight and had more photosynthate available for grain filling. Result from this experiment revealed that plant height was affected by different weeding frequencies. Double weeding (weed removal done twice) had the highest plant height followed by single weeding (weed removal once) and no weeding had the lowest. Decrease in plant height with high density of weed species may be attributed to competition for nutrition and soil water which caused reduction in crop development which was in agreement with (Oljaca et al., 2007) who reported significant decline in maize plant height due to the weeds infestation. Increased yield loss due to weed competition was associated with reduced plant height and light interception (Baldoni et al., 2000, Coleman and Gill, 2005). Weeding help plants to have more resources for growth, these results agreed with (Mubarak, 2004), (Bedry, 2007) and (El Naim and Ahmed, 2010), they found that, increasing weeding times increased plant height, due to efficient weed control. However there were no differences in plant height between flat and round varieties which could be attributed to their genetically identity. Double flat had higher plant height than round during summer and double round had higher plant height during winter but there were no statistical differences between the varieties at each season. Also, plant height was drastically reduced during winter season compared to summer season.

Weeding affected the number of days to tasseling during both seasons at both sites. No weeding plots took the longest time to reach tasseling then single weeding, while double weeding had the shortest time which implies that weeding influenced time to reach reproductive stage in maize.

Chlorophyll content index (CCI) decrease with week after tasseling (WAT) during winter season at both sites this could be due to low rainfall received during the period. No weeding plots for both seasons had low chlorophyll index compared with single and double weeding which could be due to reduction in photosynthetic rate caused by shading as a result of presence of weeds (Abouziena et al., 2007). Shaded leaves suffer from higher respiratory losses and lower water use efficiency (Page et al., 2011). Under severe weed competition (no weeding plots), maize is faced with scarcity of the needed resources. In this condition, it mobilizes the stored resource in organs like stems and leaves to allocate for grain production. Consequently, the nutrition resources in the lower leaves might primarily transferred to the plant reproduction organs. Therefore, this might be the reason that senescence could occur soon in the lower leaves in the canopy. In addition, lower leaves over-shaded by the mixed canopy are photosynthetically less active and costly for the plant to keep (Karimmojeni et al., 2010).

The stomatal self-regulation, in terms of stomatal conductance, plays an important role in overcoming water deficit periods. Reduction of SC under rainfed conditions implies that plants were able to close their stomata in order to minimise water losses causing low leaf intracellular CO_2 concentration and decreased photosynthetic rates (Lin and Sternberg, 1992). Stomatal conductance was found to vary significantly over time; these variations can be explained with the aid of the weather data. The first measurement of SC was done at 19WAP which coincided with a period where there had been no rainfall received during the past few days. As such, SC was low under rainfed conditions meaning that stomata were closed in order to avoid water loss. Tardieu and Davies (1993) suggested that in the field plant water status might have considerable influences on the way stomata behave. The closure of leaves stomata was a mechanism which maintains leaf water status, and result in transpiration, photosynthetic rates and productivity reduction (Turner, 1986, Hirayama et al., 2006).

The yield components harvest index, total biomass, cob mass, cob/plant and kernel /row during summer were statistically higher than winter planting season. In double weeding, adequate weeding was carried out which resulted in highest grain yield due to more total biomass, harvest index, number of kernel /row, number of row/cob, cob mass the highest and none weed the lowest for both planting season . Also, no weeding plot has the lowest yield components; it could be due to high weed infestation in the plot. (Abouziena et al., 2007) shown that reduction in soil moisture and nutrients had significant effect on the yield. The present results are in general agreement with those obtained by (Karimmojeni et al., 2010, El Naim and Ahmed, 2010). Low yield components obtained during winter season was as a result of low soil fertility, low temperature, erratic rainfall and deficient soil moisture during the winter (Subedi and Ma, 2009), since maize is a warmer crop and required temperature range 18-30^{o}C for optimum development (Kırtok, 1998). In regards to the interactive effect of varieties and weeding, double flat had the highest cob mass during winter while double round variety had the highest cob mass during summer season. Double round variety had the highest total biomass at both sites. The number of kernel/row and harvest index in double flat variety interaction was the highest. Weed removal once within four-eight weeks after planting also lead to better yield because shade from crops will be effective in controlling further weed growth during the remaining time to maturity (James et al., 2000). The effect of varieties (shapes) were minor on grain yield, weeding and planting seasons

3.6 Conclusion

Suitable planting seasons are very important for crops growth and development. The response of SC701 categories by shapes in different planting season was similar in each season. However, its response to the three weeding frequencies differed significantly with respect to most growth and yield parameters. The results of the study were contrary opposite to our expectations and initial hypothesis which was the possibility of planting green mealies summer and winter within a year in KwaZulu-Natal. The double weeding was expected to perform better than single and no weeding trials. However, there were little differences in the performances of the varieties under single and double weeding treatment with respect to growth and yield parameters. This result showed that flat seed had a little bit better emergences than round seed. Also, green mealies production during winter season in Umbumbulu performed generally poor with no cob to harvest, while at Ukulinga fairly poor cobs were harvested. Therefore, it was concluded that winter planting of maize resulted in low yield production most especially at Umbumbulu site. This study however, did confirm that stomatal regulation is a stress indicator. Leaf chlorophyll content was reduced by weed competition at reproductive stages of maize growth and development. Further research on the effect of single weeding (weed removal once) on growth, development and yield of SC701 and implementation of irrigation system during winter planting season for green mealies production are recommended especially at Umbumbulu site.

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CHAPTER FOUR
Effect of weeding on nutrient quality of green mealies (SC701) maize during two different planting seasons.

4.1 Introduction

Maize is ranked first as an important source of carbohydrates in Southern African for human and animal consumption (Gouse et al. 2006; FAOSTAT 2012). It is a common staple food across the world because of its high nutritional value with high levels of starch as well as valuable proteins and oils (Boyer and Shannon 2003). The starch content of maize is approximately 75% of the mature seed mass making it one of the most important crops for human food, animal feeds and other industries uses (Boyer and Shannon 2003). Similarly, simple sugars and other carbohydrates in maize are present as glucose; sucrose and fructose and they vary from 1- 3% of the kernel (Reddy et al. 2013). The starch content in maize consists of two glucose polymers which are amylose and amylopectin. In maize, amylose makes up 25 to 30% of the starch and amylopectin makes up 70 to 75% (Myers et al. 2000). The sugar content in fresh maize is high especially at 12 days after pollination, while starch is low, as the kernel matures sugars decline and starch increases (Reddy et al. 2013). According to FAOSTAT (2012), sugars were found to have reached a level of 9.4 percent of kernel dry mass in 16-day-old kernels, but the level decreased significantly with age and sucrose concentration at 15 to 18 days after pollination. These relatively high levels of reducing sugars and sucrose are possibly the main reason for sweetness in green mealies (fresh maize) hence it is so well liked by people.

The next largest chemical component of the maize kernels after starch is protein. Maize is a good source of dietary fibre and protein (Dhillon and Prasanna 2001). Protein content varies in maize varieties from about 8 to 11% of the kernel mass, which is mostly found in the endosperm (Shashdhara et al. 1988). In maize, the endosperm accounted for majority of kernel dry mass (70-90%) and it is the predominant sink of photosynthates and other assimilates during reproductive growth therefore, factors that affect endosperm development to a large extent also determine grain yield (Popp and Brumm 2003).

One of the major causes of maize yield losses is weed infestation. Apart from insufficient soil water and soil nutrients, timing of weed removal in a maize growing field is also one of the most important environmental factors that affects maize yield and its quality**.** The critical period in weed competition is influenced by many factors including nutrient status and weed density (Evans et al. 2003). According to results found by Evans et al. (2003), weed not only restricts the yield of maize but also adversely affects the maize quality in terms of protein and starch contents. There were many reports which showed that weed infestation induces water deficit in maize (Oljaca et al. 2007; Page et al. 2011). This has led to decrease in plant water potential in maize resulting in decreased water efficiency and yield reduction.

Many previous studies have focused much attention on the effects of weeds competition on the nitrogen (N) pool in the soil and dry matter accumulation within the plant. There is no doubt that weeds compete with maize for Nitrogen (N), and they may affect maize growth and development. For instance, studies have shown that controlled weeding in maize field resulted in prolonged N uptake during grain filling which was associated with extended leaf area duration and higher rates of dry matter accumulation, giving higher yields (Tollenaar and Wu 1999; Keller et al. 2012). Low N concentrations affect leaf appearance rate, cause a delay in silking, enhance leaf senescence, and decrease biomass accumulation (Evans et al. 2003). The supply of carbon and nitrogen influences the synthesis and storage of starch and protein in maize kernels. Many weeds are high-N consumers thus limiting N for crop growth (Cathcart and Swanton 2004). Weeds not only reduce the amount of N available to crops, but also the growth of many weed species is enhanced by higher soil N levels (Blackshaw et al. 2003). Furthermore, Tollenaar and Wu (1999) observed enhanced faster leaf senescence in maize subjected to high weed pressure than under weed-free conditions This may be attributed to both resource independent process and resource dependent limitations such as nutrients, water, solar radiation, and light quality changes.

There have been limited studies on the impacts of weed competition on the proline accumulation in maize. Proline accumulation occurs under various abiotic or environmental stresses including weed competition. The role of proline in cell osmotic adjustment, membrane stabilization and detoxification of injurious ions in plants exposed to stress is widely reported (Kavi Kishore et al. 2005; Ashraf and Foolad 2007). Proline is synthesized from glutamate and pyrroline-5-carboxydouble (P5C) through successive reductions catalyzed by pyrroline-5-

carboxydouble synthase (P5CS) and pyrroline-5-carboxydouble reductase (P5CR). Proline accumulation also depends on its catabolism by proline dehydrogenase (ProDH) and P5C dehydrogenase (P5CDH) (Hare and Cress 1997). Under water limited conditions, proline seems to be synthesized mostly from the glutamate pathway (Crafts-Brander and Salvucci 2002). Carbohydrates are supplied mainly through the process of photosynthesis and photosynthesis rates are usually lower in plants under weed completion, and this would furthermore lead to restriction in water availability and imbalance in nutrient uptake by plants. No studies have evaluated proline accumulation in maize competing with weeding frequencies.

Maize (SC701) is a popular hybrid in Southern Africa among small-scale farmers who practice rainfed agriculture. This variety has large cob size which is an important selection criteria by farmers for green mealies production (Fanadzo et al. 2009). In Southern Africa, green mealies are usually consumed boiled, parched, baked or as grains from roasted cobs (Shava et al. 2009; Masarirambi et al. 2011; Enayat Gholizadeh 2012). Green mealies play an important role in filling the hunger gap. However, green mealies productivity is still low although several efforts have been directed towards increasing maize yield in Africa. The objective of this study was to compare the interactive effect of weed frequencies and shapes on nutritional quality (soluble sugars, starch and protein) of SC701 maize green mealies produced during summer and winter seasons.

4.2 Material and method

4.2.1 Plant materials

The plant materials have been described in Chapter 3. Ear leaves and cobs were harvested from different weeding frequencies during summer and winter seasons from Ukulinga and Umbumbulu. The cobs were shelled and freeze dried together with the ear leaves and stored at -80°C for physiological analysis.

4.2.2 Proline determination

Proline accumulation was evaluated using the ear leaf. Proline content was determined according to the method of Bates et al. (1973). Freeze–dried leaf material was ground into a fine powder under liquid nitrogen using mortar and pestle. Subsequently, 0.5 g of ground leaf material was homogenized in 10 ml of 3% aqueous sulphosalicyclic acid. The homogenate was then filtered through Whatman® No. 2 filter paper. 2 ml of the filtrate was added to a test tube to which 2 ml of glacial acetic acid and acid ninhydrin were added, respectively. The solution was then heated in a boiling (100°C) water bath for 1 hour. The reaction was then terminated in an ice water bath. The reaction mixture was extracted with 4 ml toluene and vortexed for 15 – 20 sec. The chromosphere containing toluene was aspirated from the aqueous phase, warmed to room temperature and absorbance read at 520 nm using toluene as a blank. Proline concentration was calculated using the standard curve on a dry mass basis. The following equation was used to calculate proline:

[(µg proline/ml x ml toluene)/ (115 µg/µmole)]/ [(g sample)/5] = µmoles proline/g of dry weight material]. **Eq. 4.1**

4.2.3 Determination of soluble sugar concentration

Freeze–dried kernels were ground into a fine powder under liquid nitrogen using mortar and pestle. 0.2 g samples were mixed with 10 mL of 80% (v/v) ethanol and homogenized for 60 s. Thereafter, the mixture was incubated in a water bath (80°C) for 60 min and kept at 4°C overnight. After centrifugation at 12 000 *g* for 15 min at 4°C, the supernatant was filtered through glass wool and taken to dry in a Savant vacuum concentrator (SpeedVac, Savant, Holbrook, NY, USA). Dried samples were re-suspended in 2 mL ultra-pure water, filtered through 0.45 mm nylon filters. Sugars were analysed according to Liu and Shono (1999), using high performance liquid chromatography (HPLC, LC – 20 AT, Shimadzu Corporation, Kyoto, Japan) equipped with a refractive index detector (RID-10 A, Shimadzu Corporation, Kyoto, Japan) and a Rezex RCM–monosaccharide column (300 mm_7.8 mm) (8 mm pore size; Phenomenex, Torrance, CA, USA). The concentration of individual sugars was determined by comparison with authentic standards.

4.2.4 Total Protein content determination

The protein contents were determined using bovine serum albumin (BSA) as a standard, according to the method of Bradford (1976). 0.2 g leaf samples were homogenized in 10 ml 50 mm sodium phosphate buffer (pH 7.0) containing 1 mm EDTA-Na_2 and 2% (w/v) polyvinylpyrrolidine- 40 (PVP-40). The homogenate was centrifuged at 11 000 *g* for 15 min at 4°C, 30 µl of supernatant was added to 1 ml of Bradford solution and absorbance recorded at 595 nm for the estimation of total protein content. The protein concentration was calculated from a BSA standard curve.

4.2.5 Starch determination

Starch was determined according to Hassid and Neufeld (1964) with minor modifications. Dried pellets (0.2 g) obtained from the soluble sugar extracts were mixed with 10 ml of 35% perchloric acid in 125 ml Erlenmeyer flask and covered with foil and shaken at low speed on an orbital shaker for 30 minutes. The mixture was then suction filtered and transferred into a 100 ml volumetric flask and brought to volume using distilled water. The flask was covered and shaken to mix the solution well. Thereafter, 0.5 ml of each starch solution was added to a 15 ml test tube in a rack immersed in ice water. Six glucose standards from 0 to 50 mg/100 ml with each batch of samples were prepared. 5 ml of anthrone solution was added to each tube covered and vortexed for 10 s. Following this, tightly capped test tubes were placed in a boiling water bath for 12 min. Thereafter, the samples were allowed to cool on ice before being read at 625 nm on a spectrometer (UV- 1800 Spectrophotometer Shimadzu Corporation. Kyoto, Japan).

4.2.6 Data analyses

Data were analysed using analysis of variance (ANOVA) from GenStat® Version 14 (VSN International, UK). Thereafter, means were separated using Duncan's Multiple Range Test in GenStat® at the 5% level of significance (Appendix 3).

4.4 Results

The predominant sugars were sucrose, fructose and glucose. In summer, there were significant differences ($P<0.05$) in soluble sugar (sucrose, fructose and glucose) among weeding frequencies. However, there were no significant differences ($P>0.05$) between varieties. The interaction between varieties and weeding frequencies was not significant ($P>0.05$). The late season flat variety had the highest sucrose and fructose while no weeding round variety had the lowest sucrose and fructose at both sites (Fig 4.1). For glucose, no weeding round had the lowest value while the late weeding round had the highest values at both sites.

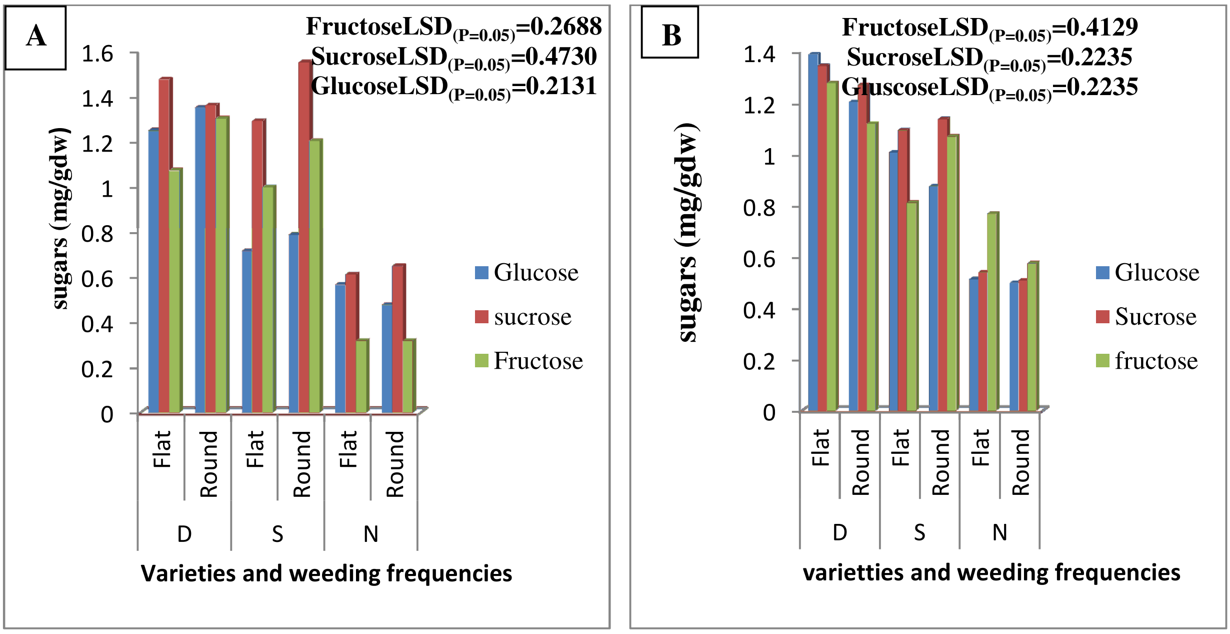

Figure 4. 1: Soluble sugars of SC701 harvested at (A) Ukulinga and (B) Umbumbulu during summer season. D = double weeding, S = single weeding and N = no weeding.

During winter, there was no yield (cobs) for Umbumbulu hence the sugar content was not evaluated. The soluble sugars (glucose, sucrose and fructose) had highly significant differences ($P<0.001$) among the weeding frequencies but no significant differences ($P>0.05$) were observed between varieties at Ukulinga. Unlike in summer, the late season weeding flat had the highest glucose concentration while none weeded round had the lowest glucose values (Fig 4.2). A similar trend as that observed during summer was observed whereby sucrose and fructose concentrations were lowest in none weeded round while late season weeding flat had the highest concentrations.

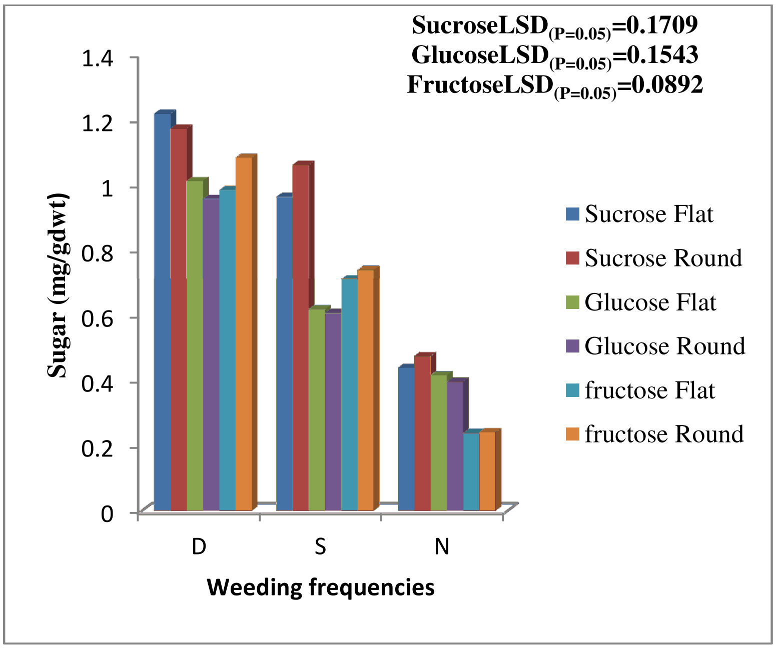

Figure 4. 2 : Soluble sugar of SC701 harvested at Ukulinga during winter season D=Double weeding, S=Single weeding and N=no weeding

4.4.1 Protein Content

With regards to Protein content during summer planting season, there were significant differences ($P<0.001$) among the weeding frequencies but no significant difference ($P>0.05$) were observed between varieties Also, there were no significant interaction ($P>0.05$) in weeding frequencies and varieties. On average in both sites, double weeding was 10.08% higher in protein content than single weeding and 50% higher than no weeding (Fig 4.3). Flat variety was higher in protein than round by 8.22%. Double weeding round (2.69 mg/g) had the highest followed by double weeding flat, single weeding flat, single weeding round, no weeding round and no weeding flat (1.28 mg/g).

During winter planting season, there were no cob harvested from Umbumbulu site, therefore protein analysis were carried out on maize grains from Ukulinga only. Highly significant differences ($P<0.001$) were observed among the weeding frequencies However, there were no significant interaction ($P>0.05$) between variety and weeding frequencies. Also, no significant differences ($P>0.05$) between flat and round varieties. Flat variety interactions with all weeding frequencies were higher compared with round variety interaction with all weeding frequencies

(Fig 4.3). Double weeding was 13.7% higher in protein than single weeding and 57.8% higher than no weeding. Flat double weeding (2.97 mg/g) had the highest protein content and lowest protein content was observed in round no weeding (1.25 mg/g).

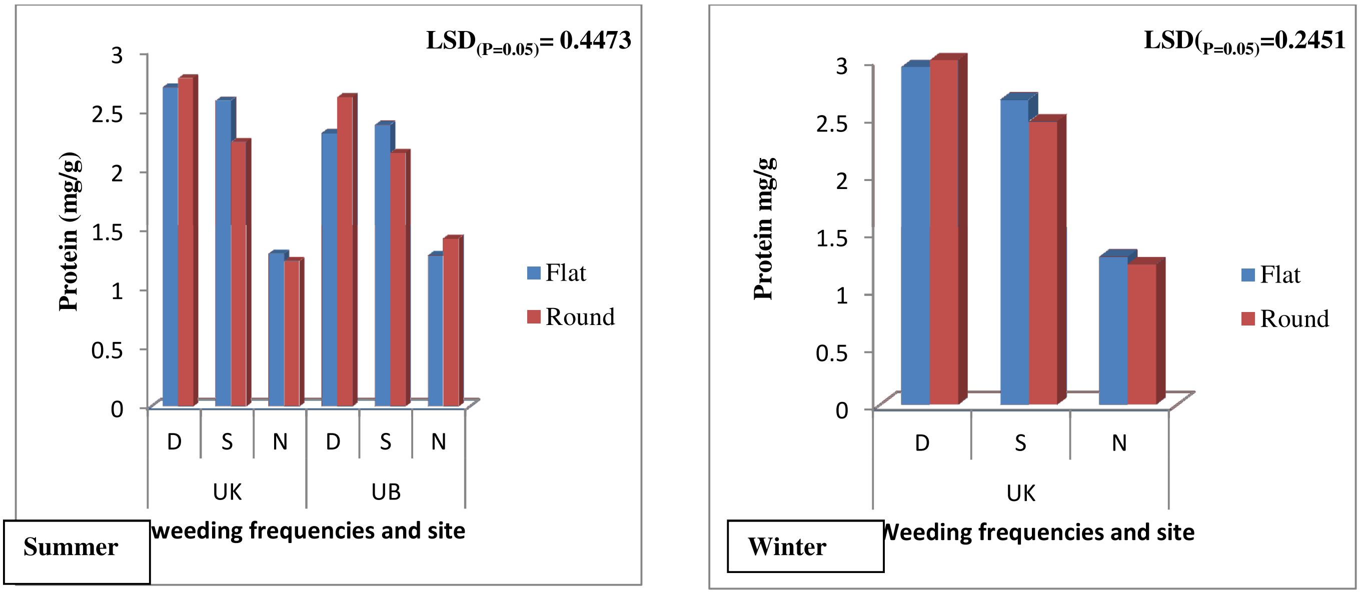

Figure 4. 3: Protein content at both sites during summer (A) and during winter planting season (B). UK= Ukulinga and UB= Umbumbulu sites. D=Double weeding, S=Single weeding and N=no weeding

4.4.2 Proline Accumulation

With regards to proline accumulation in the summer planting season, there were significant differences ($P<0.001$) between proline content at Ukulinga and Umbumbulu, also significant differences ($P<0.001$) occur among the weeding frequencies. However there were no significant differences ($P>0.05$) in proline content between varieties, also in its interaction with weeding frequencies. Proline accumulation in flat variety was 7.05% higher compared with round variety, no weeding was 47.75% higher in proline than single weeding and 49.78% higher than double weeding. During the summer planting, no weeding flat variety had the highest proline accumulation while the double weeding round had the lowest proline accumulation at both sites (Figure 4.4). Furthermore, during winter planting season there were significant differences ($P< 0.001$) among the weeding frequencies but no significant differences ($P>0.05$) in the proline accumulation between varieties. Also no significant differences (P>0.05) were observed in the interaction between varieties and weeding frequencies. No weeding had 40.04% higher proline accumulation than single weeding and 68.80% than double weeding.

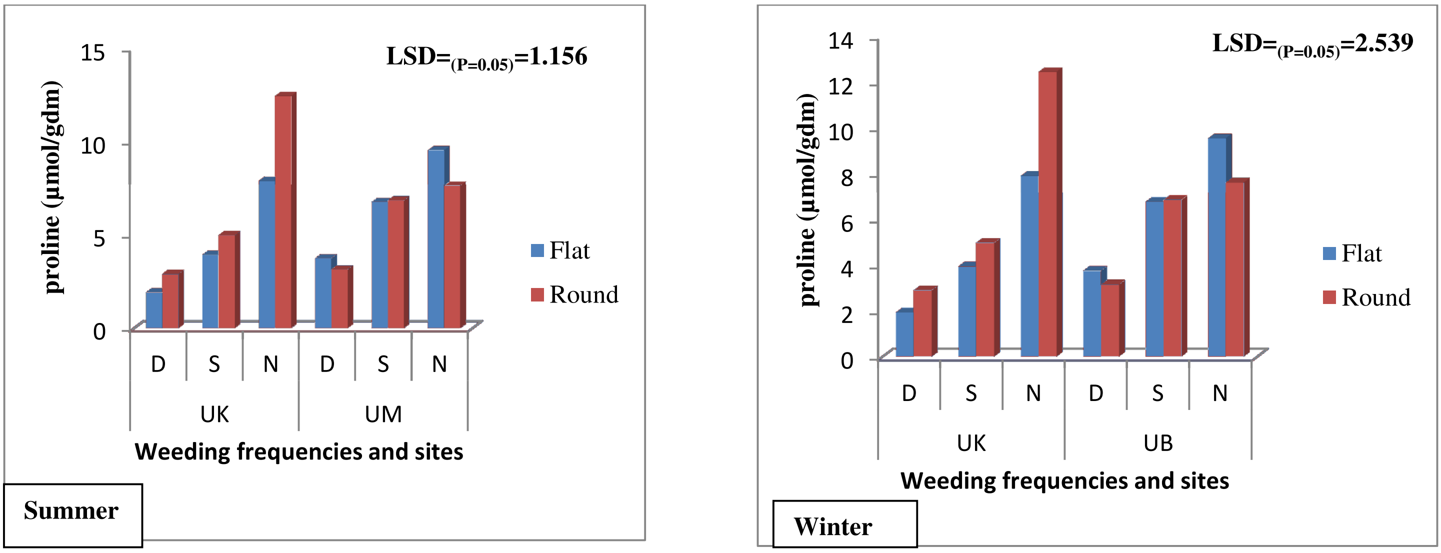

Figure 4. 4 : Proline content at both sites during summer and winter planting season. UK= Ukulinga and UB= Umbumbulu sites. D=Double weeding, S=Single weeding and N=no weeding

4.4.2 Starch content

During summer planting season, the starch content among the weeding frequencies differs significantly (P<0.001) but no significant differences (P>0.05) in maize starch were observed between Ukulinga and Umbumbulu sites. Also, there were no significant differences (P>0.05) in starch content between varieties and its interaction with weeding frequencies. Double –weeding was 9.46% higher in starch than single weeding and 33% higher than no weeding (Fig 4.5). The starch content obtained from maize at Umbumbulu was 10.21% higher than those obtained from Ukulinga site. Flat variety had higher starch content than round variety at Umbumbulu while round had higher starch content than flat at Ukulinga site. Increasing trends were observed for no weeding (2.10 mg/g) to single (2.84 mg/g) and double weeding (3.14 mg/g) at Ukulinga site while the same trend was observed for Umbumbulu site. During winter planting season at Ukulinga site, the starch content among the weeding frequencies differs significantly (P<0.001) but no significant differences in maize starch were observed between varieties. Also, there were no significant differences (P>0.05) in starch content between varieties interaction with weeding frequencies. Single weeding (11.99 mg/g) has the highest starch content followed by double weeding (10.74 mg/g) and no weeding (4.88 mg/g). The starch content in double weeding was 10.43% higher than single weeding and 59.30% than no weeding (Fig 4.5). There was no cob harvested at Umbumbulu site, therefore no starch content was determined.

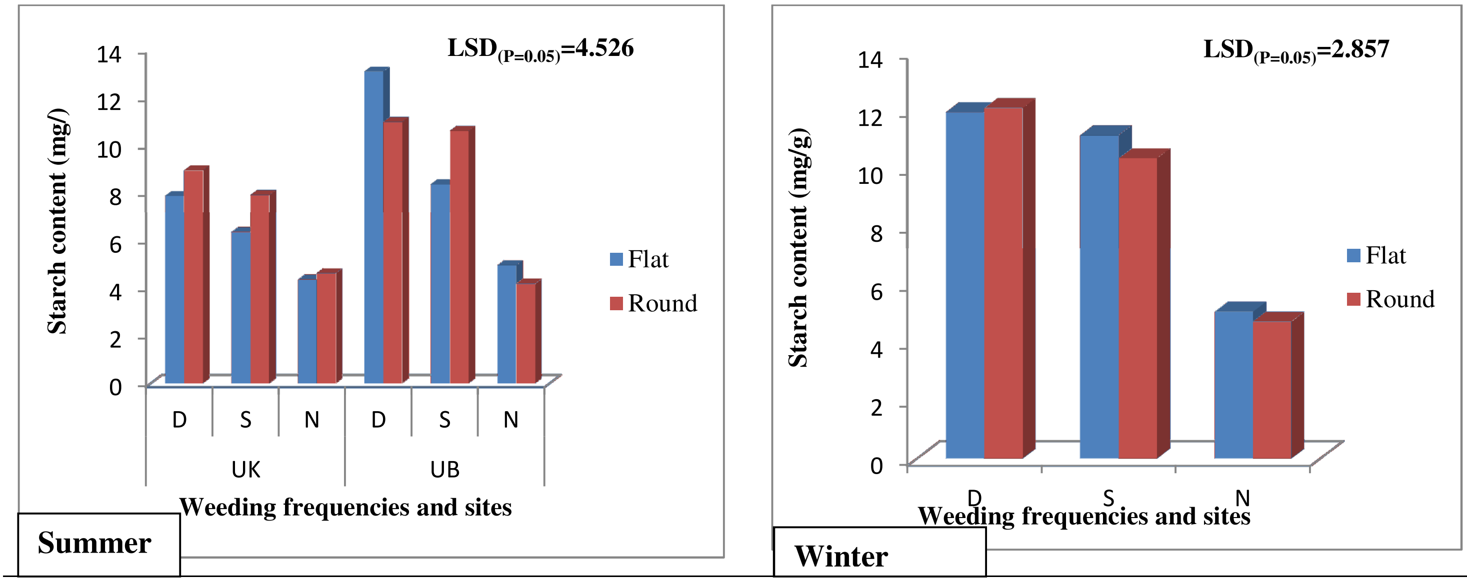

Figure 4. 5: Starch content of SC701 planted during summer and winter season at Umbumbulu and Ukulinga sites. UK= Ukulinga and UB= Umbumbulu sites. D=Double weeding, S=Single weeding and N=no weeding

4.5 Discussion

The objective of the experiment was to compare the effect of weed competition on the nutrient quality of SC701 maize green mealies. More specifically, we evaluated the impacts of weed competition on the nutrients qualities of SC701 (flat and round) hybrid planted at two different planting seasons. Starch content, total protein content, soluble sugar content and proline accumulation were used to assess the nutrient quality of the hybrid under different weeding frequencies during summer and winter season.

This experiment showed that there were differences in the starch content between the weeding frequencies with no weeding having the lowest, followed by single and double weeding. Moreover, on average, no weeding and single weeding had 59% and 10.43% reduction in starch at ukulinga site during winter while, no weeding and single weeding had 9.46% and 33% reduction in starch during summer respectively at both two sites. This could be due to no weeding plots had the highest weed density which resulted in the highest reduction in starch content. Has (2002) reported high weed density competition leads to lower starch grain and consequently reduction in maize yield. Furthermore, lower quality of maize grain in terms of starch content in the no weeding plots may be attributed to low maize growth rate and hence relatively less photosynthetic activity which resulted in less accumulation of starch (Hossain 1992). Similar results were obtained by (Randhawa et al. 2002; Randhawa 2012; Yeganehpoor et al. 2013) where it was observed that specific type of weeds influence negatively on the starch of maize. Similarly, there were no differences in the starch content at both sites during summer season. Also, no difference were observed in shapes (flat and round) at both summer and winter seasons. used in this study indicating that shape does not have any effects on the quality of maize with regards to starch content.

In regards to protein content, the impacts of weeds was mostly evident in the no weeding plots leading to lower protein content as compared to the single and double weeding. For instance, there were 51.71% reduction in protein content in no weeding plots and 9.04% reduction in single weeding as compared to double weeding during summer, this means that present of weed reduces the protein content in grains regardless its population. During winter planting season 43.84% reduction maize protein occurs in no weeding and 33.63% in single compared to double weeding. According to Tollenaar et al. (1994), high weed density result in lower grain quality in maize because weed utilizes the growth resources with high efficiency and potency which affects the morphology and phenology of the crop. The shapes (flat and round) have similarity in protein content under weeding showing that they belong to the same genetic composition. The present study are in agreement with Yeganehpoor et al. (2013) who observed that differences exist in protein content with the highest percentage protein in maize occurring when weeding was done regularly and lowest protein content was observed in maize without weeding. Previous studies have shown that the presence of weeds throughout the cultivation of crops imposed nitrogen strain on plant which directly affects protein synthesis leading to high protein content reduction

(Randhawa et al. 2002; Abouziena et al. 2007). Furthermore, Boomsma et al. (2009) observed that availability of sufficient soil nitrogen and moisture for plants can lead to higher chlorophyll contents and photosynthesis which could produce grains with higher protein contents. The improvement in protein content during the double weeding might be attributed to lesser competition for nitrogen and hence better soil moisture and nutrition availability utilized effectively by the maize crop.

Soluble sugars content (sucrose, fructose and glucose) were also different among the weeding frequencies. The soluble sugar in no weeding treatment was very low compared with double weeding. The varieties showed similar response to weeding frequencies and the interaction of shapes and weeding have no differences with regard to soluble sugar. Double weeding flat shape had higher soluble sugar than Double weeding round shape. The results of the present was however different from Williams (1971) and Weatherspoon and Schweitzer (1969) who observed that soluble sugars were not significantly affected by weeding competition in maize. Similar results was however obtained by Locke et al. (2002) who observed that sugar beet sugar content was significantly reduced as a result of weed competition.

Proline content during winter planting season was higher than proline content in the summer planting season which could be attributed to insufficient soil water. The lowest proline accumulation occurred in double weeding at both seasons. Since accumulation of proline in crops is known to be the response to abiotic stresses, the no weeding plots with the lowest water potential will have high proline level because of the stress it went through (Hare and Cress 1997; Verslues and Sharp 1999). No specific trend observed in proline between round and flat shapes showed that they are of the same genetic background.

4.6 Conclusion

The present research showed significant differences in composition of maize nutrients (protein, soluble sugar and starch) under different weeding frequencies. Highest protein, soluble sugar, starch and lowest proline accumulation were obtained in grains from double weeding while lowest nutrients quality and highest proline accumulation were observed from no weeding. Although, single weeding showed considerable higher nutrients there was no significant difference between it and double weeding. There was similarity in response of SC701varieties

(Flat and round) to weeding frequencies in regards to nutrients quality. Although, double weeding flat perform better than round varieties but there were no statistical differences between them. The practical implications are that weed removal done twice improved maize grains nutrients quality than weed removal done once, however, once weed removal within 4-8weeks after planting still maintain the grain nutrient quality because the shading by the crop will be effective in controlling further weed growth during the remaining time to maturity.

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CHAPTER FIVE

General discussion and conclusions

Weed competition remains a major cause of concern to global food production. Agronomic practices such as weeding, critical period for weeding, planting season selection and its effect on yields of selected maize hybrids have not been fully explored for rain-fed agriculture by researchers in South Africa. While rainfall still remains the most important limiting factor for increasing yield of maize in South Africa (Machethe et al. 2004), competition from weeds during the early growth period is also a critical agronomic factor which causes losses greater than 30% from maize yield (Rajcan and Swanton 2001; Liu et al. 2009). Information describing agronomic practices such as weeding and timing of planting in green mealies is still limited (Shava et al. 2009). The review of literature suggested that green mealies production could contribute significantly towards ensuring food security given that proper agronomic practices are followed (Masarirambi et al. 2011). Local farmers in KwaZulu–Natal commonly cultivate the SC701 maize hybrid for green mealies; this is usually during the summer season. It is not yet known if green mealies from the high yielding SC701 maize hybrid could be grown twice in a warm climatic region like KwaZulu-Natal. Furthermore, the impact of seed size on the performance of SC701 has not yet been documented. Therefore, the present study was conducted to evaluate (i) the possibility of growing green mealies using the SC701 hybrid twice within a year (winter and summer), (ii) the interactive effect of seed shape and weeding frequency on yield of SC701 maize hybrid planted under rain-fed conditions, and (iii) the effect of weed competition on nutrient quality of SC701 maize green mealies. The germination characteristics of SC701 seed consist of basic information required when studying aspects of any crop especially during low and high temperatures. This is because growth parameters such as emergence and good stand establishment depend on temperature and quality of seeds. Therefore, it was imperative for the current study to determine the quality of maize seeds; this was done on a comparative basis with respect to seed size, shape and different temperature regimes (Chapter 2). Statistical differences were observed for germination rate (GR), germination velocity index (GVI) and vigour index (VI) but no significant differences in germination mean time (GMT) and final germination in all the varieties at different temperatures. This result showed that flat seed germinated faster than round seeds at constant temperatures while small seeds germinated faster than large seeds. Seed germinated at 20/30°C had the highest VI compared to seeds germinated at 15/20, 20 and 30°C. This result suggested that flat–small seeds germinated faster at constant than alternating temperatures.

The standard germination test values cannot be directly used to predict field emergence and its effect on yield. Comparing these results with those of field emergence was therefore essential. Therefore, the interactive effect of seed shape and weeding frequency on SC701 planted at low soil temperature (winter season) and warm temperature (summer season) was evaluated in Chapter 3. The objective of this study was to determine the combined effect of seed shape and weeding frequency on growth and development of green mealies. The expectation was that the flat variety would perform better in emergence than round since the seed quality test showed faster germination rate in flat than round seeds. However, no statistical difference between the varieties (flat and round) was observed with respect to field emergence. This was in contrast with previous reports by Mazur and Feranec (1994) who observed that seed shape of maize had significant variations in yield and emergence. Results of this study also revealed that maize produced high yield under double weeding and that seed shape had little or no influence on yield. Several studies have showed that maize was very sensitive to weed competition and that time of weed removal influenced yield (Gab-Alla et al. 1985; Gouse et al. 2006; Ali et al. 2011; Page et al. 2011). Maize and weeds interfere with growth activities of each other to a varying degree and compete for water, mineral nutrients, and solar radiation and hinder harvest operations (Gouse et al. 2006; FAOSTAT 2012).

Since, one of the aims of this study was to explore the possibility of planting green mealies twice in a year, the growth, yield and nutrient characteristics of the maize planted during summer and winter seasons were compared. The result of this study showed that green mealies production during summer emerged faster than winter season; this was due to favourable growing conditions (temperature and soil water) during summer. Results for vigour index, daily germination rate, germination velocity index obtained from the seed quality at varying temperatures (Chapter 2) verified results obtained from the field trial (Chapter 3) with respect to temperature. In addition, the results showed that summer planting favoured both vegetative and reproductive growth compared with winter planting. This translated into higher yields during summer than for the winter planted crop. Results of the field trial confirmed the fact that maize is a warm season crop and that winter maize cultivation production may require supplementary irrigation in order to obtain good yield. Reports in the literature indicated that optimum temperatures for maize growth were in the range of 18 to 30°C. Seed shape (flat and round) had no effect on yield of the SC701 maize hybrid. It can be concluded that such similarities were due to their similar genetic makeup.

In addition, nutritional quality analysis was carried out on harvested grains to determine whether the reduction in yield caused by weed competition affected the nutritional quality of green mealies (chapter 4). Results showed that green mealies had the highest protein, starch and soluble sugar contents when weeded twice during the growing season compared to weeding once and no weeding, respectively. The low in nutrient composition observed in green mealies from plots that were not weeded suggests that high weed density had a negative effect on kernel quality (protein, sugar and starch). This was possibly due to low crop growth rate and low photosynthetic activity in maize plants due to competition from weeds (Tollenaar et al. 1994). The results showed that highest leaf proline accumulation was observed plants from plots that were not weeded while the lowest proline accumulation was observed in plants from the double weeding plots. This suggests that maize plants in plots that were not weeded experienced stress. Such stress could have been the result of depleted soil water and nutrients due to competition from weeds. According to Hare and Cress (1997), accumulation of proline in crops is known to be among the response to abiotic stresses.

In conclusion, results obtained from this study suggest that weed competition was limiting to growth, development and productivity of maize. The fact that maize performed well under single weeding during summer and still produced reasonable yield under single weeding suggests that farmers producing green mealies can still obtain fairly high yield if weed removal is carried out within five-six weeks after planting. It is recommended that maize farmers, most specifically SC701 maize hybrid, should avoid weed competition during the vegetative growth stage (four – eight weeks after planting). Further research is needed to be carried out to evaluate growth, yield and nutritional characteristics of SC701 under irrigated conditions for both seasons. Moreover, it will be of high benefit to evaluate the impacts of weed competition on growth, yield and nutrients of SC701 maize under irrigated conditions.

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APPENDICES

Appendix 1: List of ANOVAs for seed germination study (Chapter two)

Variate: Daily germination %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	168.40	84.20	2.98	
rep.*Units* stratum					
Temperature ^{o}C	3	35382.93	11794.31	417.74	<.001
Seed group	3	3133.87	1044.62	37.00	<.001
Day	6	342801.07	85700.27	3035.38	<.001
Temperature ^{o}C.variety	9	2483.73	275.97	9.77	<.001
Temperature ^{o}C.day	12	39667.73	3305.64	117.08	<.001
Seed group.day	12	2458.13	204.84	7.26	<.001
Temperature ^{o}C.seed group.day	36	3113.60	86.49	3.06	<.001
Residual	158	4460.93	28.23		
Total	239	433670.40			

CV=9.7%

Variate: GVI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	7.778	3.889	1.87	
rep.*Units* stratum					
Seed group	3	98.579	32.860	15.78	<.001
Temperature	3	1781.643	593.881	285.25	<.001
Seed group. Temperature	9	134.980	14.998	7.20	<.001
Residual	30	62.459	2.082		
Total	47	2085.438			

CV%=7.6

Variate: Final Germination%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2.000	1.000	1.00	
Rep.*Units* stratum					
Seed group	3	3.667	1.222	1.22	0.319
Temperature	3	3.667	1.222	1.22	0.319
Seeed group. Temperature	9	5.667	0.630	0.63	0.763
Residual	30	30.000	1.000		

Total 47 45.000

CV=1.0%

Variate: Mean Germination Time

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.005000	0.002500	1.00	
rep.*Units* stratum					
Seed group	3	0.009167	0.003056	1.22	0.319
Temperature	3	0.009167	0.003056	1.22	0.319
Seed group. Temperature	9	0.014167	0.001574	0.63	0.763
Residual	30	0.075000	0.002500		

Total 47 0.112500

CV=1.0%

Variate: Germination rate

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	98.00	49.00	0.89	
rep.*Units* stratum					
Seed group	3	633.00	211.00	3.83	0.020
Temperature	3	29499.67	9833.22	178.64	<.001
Seed group. Temperature	9	1515.00	168.33	3.06	0.010
Residual	30	1651.33	55.04		
Total	47	33397.00			

CV=31.9%

Variate: Vigour index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Seed group	3	22179.	7393.	0.87	0.466
Temperature	3	868788.	289596.	34.14	<.001
Seed group. Temperature	9	1066276.	118475.	13.97	<.001
Residual	32	271470.	8483.		
Total	47	2228713.			

CV=16.1%

Variate: fresh mass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.04655	0.02328	1.75	
rep.*Units* stratum					
Seed group	3	0.58083	0.19361	14.53	<.001
Temperature ^{o}C	3	5.84800	1.94933	146.27	<.001
Seed group.Temperature ^{o}C	9	0.55648	0.06183	4.64	<.001
Residual	30	0.39981	0.01333		
Total	47	7.43167			

CV=6.5%

Variate: dry mass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.000963	0.000481	0.42	
rep.*Units* stratum					
Seed group	3	0.190175	0.063392	54.81	<.001
Temperature_oC	3	0.018714	0.006238	5.39	0.004
Seed group.Temperature_oC	9	0.072285	0.008032	6.94	<.001
Residual	30	0.034698	0.001157		
Total	47	0.316836			

CV=8.3%

Variate: shoot length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	4.4291	2.2145	3.03	
rep.*Units* stratum					
Seed group	3	2.6268	0.8756	1.20	0.327
Temperature °C	3	189.0889	63.0296	86.33	<.001
Seed group.Temperature °C	9	8.3446	0.9272	1.27	0.293
Residual	30	21.9026	0.7301		
Total	47	226.3920			
CV=14.9%					

Variate: Root length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	11.726	5.863	1.53	
rep.*Units* stratum					
Seed group	3	8.187	2.729	0.71	0.553
Temperature °C	3	448.422	149.474	38.97	<.001
Seed group.Temperature °C	9	44.091	4.899	1.28	0.289
Residual	30	115.077	3.836		
Total	47	627.503			
CV=14.1%					

Variate: Root: Shoot

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.02197	0.01098	1.03	
rep.*Units* stratum					
Seed group	3	0.04419	0.01473	1.37	0.269
Temperature °C	3	34.18627	11.39542	1063.73	<.001
Seed group.Temperature °C	9	0.23166	0.02574	2.40	0.035
Residual	30	0.32138	0.01071		

Total	47	34.80546

CV=11.8%

Appendix 2: List of ANOVAs for field trials (Chapter three)

Winter plant height

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.	
Rep stratum	3		622.60	207.53	7.20		
Rep.*Units* stratum							
planting site	1		105331.40	105331.40	3654.93	<.001	
Weeding_Frequency	2		33947.48	16973.74	588.98	<.001	
Seed shape	1		134.55	134.55	4.67	0.031	
WAP	15		213954.10	14263.61	494.94	<.001	
plantingsite.WeedingFrequency	2		13261.14	6630.57	230.08	<.001	
planting_site.Seed shape	1		45.87	45.87	1.59	0.208	
Weeding_Frequency.Seed shape	2		1038.27	519.13	18.01	<.001	
planting_site.WAP	14	(1)	53323.54	3808.82	132.16	<.001	
Weeding_Frequency.WAP	30		24825.85	827.53	28.71	<.001	
Seed shape.WAP	15		200.69	13.38	0.46	0.958	
plantingsite.WeedingFrequency.Seed shape		2		1975.30	987.65	34.27	<.001
plantingsite.WeedingFrequency.WAP	28	(2)	9844.30	351.58	12.20	<.001	
planting_site.Seed shape.WAP	14	(1)	196.31	14.02	0.49	0.941	
Weeding .Frequency.Seed shape.WAP	30		532.17	17.74	0.62	0.948	
plantingsite.WeedingFrequency.Seed shapeWAP	28	(2)	687.11	24.54	0.85	0.687	
Residual	539	(34)	15533.43	28.82			
Total	727	(40)	464671.05				

CV=16.7%

Variate: Winter Leaf_Number

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	3		2.3897	0.7966	1.53	
Rep.*Units* stratum						
site	1		20.5845	20.5845	39.58	<.001
Seed shape	1		6.9571	6.9571	13.38	<.001
Weeding_Frequency	2		0.0697	0.0349	0.07	0.935
WAP	11	(1)	3539.5224	321.7748	618.78	<.001
site.Seed shape	1		25.6784	25.6784	49.38	<.001
site.Weeding_Frequency	2		2.7093	1.3547	2.61	0.075
Seed shape.Weeding_Frequency	2		3.5131	1.7566	3.38	0.035
site.WAP	7	(5)	230.2389	32.8913	63.25	<.001
Seed shape.WAP	11	(1)	6.5325	0.5939	1.14	0.327
Weeding_Frequency.WAP	22	(2)	30.1221	1.3692	2.63	<.001
site.Seed shape.Weeding_Frequency	2		1.6406	0.8203	1.58	0.208
site.Seed shape.WAP	7	(5)	10.7667	1.5381	2.96	0.005
site.Weeding_Frequency.WAP	14	(10)	9.1472	0.6534	1.26	0.233
Seed shape.Weeding_Frequency.WAP	22	(2)	15.9944	0.7270	1.40	0.111
site.Seed shape.Weeding_Frequency.WAP	14	(10)	1.9394	0.1385	0.27	0.997
Residual	357	(108)	185.6444	0.5200		
Total	479	(144)	3842.1980			

CV=8.9%

Variate: winter Soil Water Content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		140.37	70.18	1.90	
Rep.*Units* stratum						
planting_site	1		60088.44	60088.44	1623.56	<.001
weeding_frequency	2		69.95	34.97	0.94	0.390

Seed shape	1		3.04	3.04	0.08	0.774
WAP	17	(1)	6793.42	399.61	10.80	<.001
plantingsite.weedingfrequency	2		112.70	56.35	1.52	0.219
planting_site.Seed shape	1		6.16	6.16	0.17	0.683
weeding_frequency.Seed shape	2		72.83	36.41	0.98	0.375
planting_site.WAP	17	(1)	1860.85	109.46	2.96	<.001
weeding_frequency.WAP	34	(2)	1228.93	36.15	0.98	0.509
Seed shape.WAP	17	(1)	387.31	22.78	0.62	0.880
planting_site.weeding_frequency.Seed shape	2		64.52	32.26	0.87	0.419
planting_site.weeding_frequency.WAP	34	(2)	1061.43	31.22	0.84	0.721
planting_site.Seed shape.WAP	17	(1)	234.96	13.82	0.37	0.990
weeding_frequency.Seed shape.WAP	34	(2)	855.71	25.17	0.68	0.915
planting_site.weeding_frequency.Seed shape.WAP	34	(2)	968.02	28.47	0.77	0.823
Residual	413	(41)	15285.27	37.01		
Total	630	(53)	85808.85			

CV=25.2%

Variate: Field emergences emergence%

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	3		1034.6	344.9	0.84	
Rep.*Units* stratum						
Planting seasons	1		6562.2	6562.2	16.06	<.001
planting_site	1		2245.5	2245.5	5.49	0.022
Weeding_Frequency	2		131.6	65.8	0.16	0.852
Seed shape	1		34.7	34.7	0.08	0.772
Planting_date.planting_site	1		175.3	175.3	0.43	0.515
Planting_date.Weeding_Frequency	2		919.8	459.9	1.13	0.331
planting_site.Weeding_Frequency	2		220.8	110.4	0.27	0.764
Planting_date.Seed shape	1		139.5	139.5	0.34	0.561
planting_site.Seed shape	1		2.1	2.1	0.01	0.943
Weeding_Frequency.Seed shape	2		205.7	102.9	0.25	0.778

Planting_date.planting_site.Weeding_Frequency	2		286.5	143.2	0.35	0.706
Planting_date.planting_site.Seed shape	1		28.5	28.5	0.07	0.793
Planting_date.Weeding_Frequency.Seed shape	2		1353.9	676.9	1.66	0.198
planting_site.Weeding_Frequency.Seed shape	2		508.9	254.5	0.62	0.540
Planting_date.planting_site.Weeding_Frequency.Seed shape	2		572.2	286.1	0.70	0.500
Residual	68	(1)	27789.9	408.7		
Total	94	(1)	41932.1			

CV=23.8%

Variate: Winter DAP 50% tasseling

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	12.17	4.06	0.29	
Rep.*Units* stratum					
weeding_frequency	2	777.00	388.50	27.45	<.001
Seed shape	1	42.67	42.67	3.01	0.103
weeding_frequency.Seed shape	2	22.33	11.17	0.79	0.472
Residual	15	212.33	14.16		
Total	23	1066.50			

CV=3.0%

Variate: CCI

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
rep stratum	3		4.134	1.378	0.44	
rep.*Units* stratum						
planting_site	1		892.210	892.210	283.19	<.001
weeding_frequency	2		333.850	166.925	52.98	<.001
Seed shape	3		14.620	4.873	1.55	0.206
WAP	3		816.066	272.022	86.34	<.001
planting_site.weeding_frequency	2		155.643	77.822	24.70	<.001
weeding_frequency.Seed shape	6		30.269	5.045	1.60	0.152

planting_site.WAP	3		381.578	127.193	40.37	<.001	
weeding_frequency.WAP	6		69.436	11.573	3.67	0.002	
Seed shape.WAP	9		40.709	4.523	1.44	0.180	
planting_site.weeding_frequency.WAP	6		49.837	8.306	2.64	0.019	
weeding_frequency.Seed shape.WAP		18		25.694	1.427	0.45	0.972
Residual	125	(4)	393.821	3.151			
Total	187	(4)	3136.054				

CV=17.1%

Variate: Winter SC

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.	
rep stratum	3		1267.3	422.4	1.94		
rep.*Units* stratum							
planting_sites	1		47801.0	47801.0	219.05	<.001	
weeding_frequency	2		516.1	258.0	1.18	0.310	
Seed shape	1		371.3	371.3	1.70	0.194	
WAP	3		4906.3	1635.4	7.49	<.001	
planting_season.weeding_frequency	2		385.1	192.6	0.88	0.416	
planting_season.Seed shape	1		0.5	0.5	0.00	0.963	
weeding_frequency.Seed shape	2		64.4	32.2	0.15	0.863	
planting_season.WAP	3		3557.6	1185.9	5.43	0.001	
weeding_frequency.WAP	6		1895.8	316.0	1.45	0.201	
Seed shape.WAP	3		3182.4	1060.8	4.86	0.003	
planting_season.weeding_frequency.Seed shape	2		22.4	11.2	0.05	0.950	
planting_season.weeding_frequency.WAP	6		2202.8	367.1	1.68	0.130	
planting_season.Seed shape.WAP	3		954.8	318.3	1.46	0.229	
weeding_frequency.Seed shape.WAP		6		285.7	47.6	0.22	0.970
planting_season.weeding_frequency.Seed shape.WAP		6		584.6	97.4	0.45	0.846
Residual	140	(1)	30550.5	218.2			
Total	190	(1)	98257.3				

CV=28.3%

Variate: Winter Total_biomass

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	3		1890.4	630.1	0.65	
Rep.*Units* stratum						
planting_site	1		31.1	31.1	0.03	0.859
Weeding_Frequency	2		19134.6	9567.3	9.87	<.001
Seed shape	1		105.4	105.4	0.11	0.744
planting_site.Weeding_Frequency	2		27701.5	13850.7	14.29	<.001
planting_site.Seed shape	1		4.8	4.8	0.00	0.944
Weeding_Frequency.Seed shape	2		1452.3	726.2	0.75	0.481
planting_site.Weeding_Frequency.Seed shape	2		3750.9	1875.4	1.94	0.161
Residual	32	(1)	31014.4	969.2		
Total	46	(1)	84797.6			

CV=30.8%

Variate: Winter HI

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	3		0.03970	0.01323	1.12	
Rep.*Units* stratum						
Weeding_Frequency	1	(1)	0.10127	0.10127	8.55	0.022
Seed shape	1		0.00118	0.00118	0.10	0.761
Weeding_Frequency.Seed shape	1	(1)	0.05006	0.05006	4.23	0.079
Residual	7	(8)	0.08292	0.01185		
Total	13	(10)	0.21795			

Cv=28.7%

Variate:Winter cob_mass

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	3		14936.	4979.	1.84	
Rep.*Units* stratum						
Weeding_Frequency	1	(1)	16243.	16243.	6.00	0.044
Seed shape	1		61.	61.	0.02	0.885
Weeding_Frequency.Seed shape	1	(1)	318.	318.	0.12	0.742
Residual	7	(8)	18948.	2707.		
Total	13	(10)	34221.			

CV=34.7%

Variate: Kernel_row

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	3		52.95	17.65	0.90	
Rep.*Units* stratum						
Weeding Frequency	2		345.69	172.84	8.78	0.010
Seed shape	1		1.22	1.22	0.06	0.809
Weeding_Frequency.Seed shape	1	(1)	0.20	0.20	0.01	0.923
Residual	8	(7)	157.57	19.70		
Total	15	(8)	322.64			

CV=18.8%

Variate: row kernel

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	3		4.4889	1.4963	2.17	
Rep.*Units* stratum						
Weeding Frequency	2		1.4717	0.7359	1.07	0.388
Seed shape	1		0.1141	0.1141	0.17	0.695
Weeding_Frequency.Seed shape	1	(1)	6.8179	6.8179	9.89	0.014

Residual	8	(7)	5.5139	0.6892
Total	15	(8)	14.1944	

CV=6.7%

Variate: Summer Plant_height

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	3		1084.3	361.4	2.71	
Rep.*Units* stratum						
Weeding_Frequency	2		3740.4	1870.2	14.00	<.001
site	1		5.9	5.9	0.04	0.834
Seed shape	1		403.9	403.9	3.02	0.083
WAP	11	(1)	1324147.7	120377.1	901.42	<.001
Weeding_Frequency.site	2		983.8	491.9	3.68	0.026
Weeding_Frequency.Seed shape	2		2031.8	1015.9	7.61	<.001
site.Seed shape	1		3857.0	3857.0	28.88	<.001
Weeding_Frequency.WAP	22	(2)	8080.7	367.3	2.75	<.001
site.WAP	7	(5)	11596.7	1656.7	12.41	<.001
Seed shape.WAP	11	(1)	1421.2	129.2	0.97	0.476
Weeding_Frequency.site.Seed shape	2		704.1	352.0	2.64	0.073
Weeding_Frequency.site.WAP	14	(10)	10096.9	721.2	5.40	<.001
Weeding_Frequency.Seed shape.WAP	22	(2)	4021.2	182.8	1.37	0.126
site.Seed shape.WAP	7	(5)	2872.7	410.4	3.07	0.004
Weeding_Frequency.site.Seed shape.WAP	14	(10)	2479.7	177.1	1.33	0.189
Residual	357	(108)	47674.4	133.5		
Total	479	(144)	1356520.3			

CV=12.4%

Variate: Summer Leaf_Number

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	3		2.3897	0.7966	1.53	
Rep.*Units* stratum						
WAP	11	(1)	3539.5224	321.7748	618.78	<.001
Weeding_Frequency	2		0.0697	0.0349	0.07	0.935
site	1		20.5845	20.5845	39.58	<.001
Seed shape	1		6.9571	6.9571	13.38	<.001
WAP.Weeding_Frequency	22	(2)	30.1221	1.3692	2.63	<.001
WAP.site	7	(5)	230.2389	32.8913	63.25	<.001
Weeding_Frequency.site	2		2.7093	1.3547	2.61	0.075
WAP.Seed shape	11	(1)	6.5325	0.5939	1.14	0.327
Weeding_Frequency.Seed shape	2		3.5131	1.7566	3.38	0.035
site.Seed shape	1		25.6784	25.6784	49.38	<.001
WAP.Weeding_Frequency.site	14	(10)	9.1472	0.6534	1.26	0.233
WAP.Weeding_Frequency.Seed shape	22	(2)	15.9944	0.7270	1.40	0.111
WAP.site.Seed shape	7	(5)	10.7667	1.5381	2.96	0.005
Weeding_Frequency.site.Seed shape	2		1.6406	0.8203	1.58	0.208
WAP.Weeding_Frequency.site.Seed shape	14	(10)	1.9394	0.1385	0.27	0.997
Residual	357	(108)	185.6444	0.5200		
Total	479	(144)	3842.1980			

CV=8.9%

Variate: Summer Soil water Content

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		29.74	14.87	0.73	
Rep.*Units* stratum						
planting_site	1		46836.62	46836.62	2313.24	<.001
weeding_frequency	2		139.81	69.91	3.45	0.033
Seed shape	1		877.29	877.29	43.33	<.001

WAP	14	(1)	8351.57	596.54	29.46	<.001
planting_site.weeding_frequency	2		238.32	119.16	5.89	0.003
planting_site.Seed shape	1		25.57	25.57	1.26	0.262
weeding_frequency.Seed shape	2		601.89	300.94	14.86	<.001
planting_site.WAP	10	(5)	2850.94	285.09	14.08	<.001
weeding_frequency.WAP	28	(2)	2737.23	97.76	4.83	<.001
Seed shape.WAP	14	(1)	6436.02	459.72	22.71	<.001
planting_site.weeding_frequency.Seed shape	2		52.66	26.33	1.30	0.274
planting_site.weeding_frequency.WAP	20	(10)	563.98	28.20	1.39	0.123
planting_site.Seed shape.WAP	10	(5)	751.29	75.13	3.71	<.001
weeding_frequency.Seed shape.WAP	28	(2)	4086.34	145.94	7.21	<.001
planting_site.weeding_frequency.Seed shape.WAP	20	(10)	505.65	25.28	1.25	0.213
Residual	310	(72)	6276.64	20.25		
Total	467	(108)	58934.15			

CV=17.2%

Variate: Summer Chlorophyll content index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	3	45.45	15.15	0.96	
rep.*Units* stratum					
Site	1	5300.08	5300.08	334.40	<.001
WAP	4	2213.87	553.47	34.92	<.001
Seed shape	1	8.63	8.63	0.54	0.462
weeding_frequency	2	362.96	181.48	11.45	<.001
Site.WAP	4	1452.75	363.19	22.91	<.001

Site.Seed shape	1	81.90	81.90	5.17	0.024
WAP.Seed shape	4	44.46	11.11	0.70	0.592
Site.weeding_frequency	2	47.17	23.59	1.49	0.229
WAP.weeding_frequency	8	201.65	25.21	1.59	0.131
Seed shape.weeding_frequency	2	5.85	2.92	0.18	0.832
Site.WAP.Seed shape	4	149.86	37.47	2.36	0.055
Site.WAP.weeding_frequency	8	216.80	27.10	1.71	0.099
Site.Seed shape.weeding_frequency	2	180.90	90.45	5.71	0.004
WAP.Seed shape.weeding_frequency	8	143.58	17.95	1.13	0.344
Site.WAP.Seed shape.weeding_frequency	8	145.29	18.16	1.15	0.335
Residual	177	2805.37	15.85		
Total	239	13406.56			

CV=24.7%

Variate: summer Stomatal conductance

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	3	1415.5	471.8	0.85	
rep.*Units* stratum					
Site	1	2065.2	2065.2	3.70	0.056
Seed shape	1	762.8	762.8	1.37	0.244
WAP	3	62244.2	20748.1	37.16	<.001
weeding_frequency	2	162.2	81.1	0.15	0.865
Site.Seed shape	1	0.0	0.0	0.00	0.996
Site.WAP	3	18591.3	6197.1	11.10	<.001

Seed shape.WAP	3	2683.0	894.3	1.60	0.192
Site.weeding_frequency	2	966.9	483.5	0.87	0.423
Seed shape.weeding_frequency	2	191.9	96.0	0.17	0.842
WAP.weeding_frequency	6	3239.3	539.9	0.97	0.450
Site.Seed shape.WAP	3	2836.7	945.6	1.69	0.171
Site.Seed shape.weeding_frequency	2	441.1	220.5	0.39	0.674
Site.WAP.weeding_frequency	6	2154.0	359.0	0.64	0.696
Seed shape.WAP.weeding_frequency	6	1964.9	327.5	0.59	0.741
Site.Seed shape.WAP.weeding_frequency	6	896.6	149.4	0.27	0.951
Residual	141	78721.0	558.3		

Total 191 179336.5

CV=33.9%

Variate: Summer_HI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	3	26.79	8.93	0.85	
rep.*Units* stratum					
planting_site	1	89.94	89.94	8.56	0.006
weeding_frequency	2	214.70	107.35	10.22	<.001
Seed shape	1	1.92	1.92	0.18	0.672
planting_site.weeding_frequency	2	63.79	31.90	3.04	0.062
planting_site.Seed shape	1	7.85	7.85	0.75	0.394
weeding_frequency.Seed shape					

	2	0.32	0.16	0.02	0.985
planting_site.weeding_frequency.Seed shape	2	21.73	10.86	1.03	0.367
Residual	33	346.55	10.50		

Total 47 773.59

CV=12.9%

Variate: Summer cob mass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	3	6154.	2051.	0.67	
rep.*Units* stratum					
planting_site	1	23048.	23048.	7.52	0.010
weeding_frequency	2	22353.	11177.	3.65	0.037
Seed shape	1	1224.	1224.	0.40	0.532
planting_site.weeding_frequency	2	1844.	922.	0.30	0.742
planting_site.Seed shape	1	5654.	5654.	1.84	0.184
weeding_frequency.Seed shape	2	2066.	1033.	0.34	0.716
planting_site.weeding_frequency.Seed shape	2	8905.	4453.	1.45	0.249
Residual	33	101146.	3065.		

Total 47 172395.

CV=34.9%

Variate: Summer no of kernel row

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	211.53	70.51	3.45	

```
rep.*Units* stratum
planting_site                        1    3386.04    3386.04   165.79   <.001
weeding_frequency                    2     341.03     170.52     8.35   0.001
Seed shape                           1       3.03       3.03     0.15   0.703
planting_site.weeding_frequency
                                     2     262.20     131.10     6.42   0.004
planting_site.Seed shape             1       1.98       1.98     0.10   0.757
weeding_frequency.Seed shape
                                     2      25.51      12.75     0.62   0.542
planting_site.weeding_frequency.Seed shape
                                     2      11.18       5.59     0.27   0.762
Residual                            33     673.99      20.42
Total    47       4916.48
```

CV=23.6%

Variate: no_of_row_kernel

```
Source of variation                d.f.      s.s.       m.s.     v.r.   F pr.
rep stratum                          3       4.56       1.52     0.15
rep.*Units* stratum
planting_site                        1    2057.36    2057.36   197.02   <.001
weeding_frequency                    2     233.37     116.69    11.17   <.001
Seed shape                           1       4.41       4.41     0.42   0.520
planting_site.weeding_frequency
                                     2     146.66      73.33     7.02   0.003
planting_site.Seed shape             1       3.83       3.83     0.37   0.549
weeding_frequency.Seed shape
                                     2       0.11       0.06     0.01   0.995
planting_site.weeding_frequency.Seed shape
                                     2       0.39       0.19     0.02   0.982
Residual                            33     344.60      10.44
Total                               47    2795.28
```

CV=18%

Variate: Summer cob/plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	3	0.03935	0.01312	0.66	
rep.*Units* stratum					
planting_site	1	0.00231	0.00231	0.12	0.735
weeding_frequency	2	0.04977	0.02488	1.25	0.299
Seed shape	1	0.02083	0.02083	1.05	0.313
planting_site.weeding_frequency	2	0.01505	0.00752	0.38	0.688
planting_site.Seed shape	1	0.00231	0.00231	0.12	0.735
weeding_frequency.Seed shape	2	0.08681	0.04340	2.19	0.128
planting_site.weeding_frequency.Seed shape	2	0.01505	0.00752	0.38	0.688
Residual	33	0.65509	0.01985		
Total	47	0.88657			

CV=12.9%

Appendix 3: List of ANOVAs for nutrient quality (chapter four)

Variate: Summer starch (mg/g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.2037	0.0679	0.27	
rep.*Units* stratum					
site	1	1.0068	1.0068	3.94	0.055
weed_frequency	2	9.1372	4.5686	17.89	<.001
Seed shape	1	0.0402	0.0402	0.16	0.694
site.weed_frequency	2	0.5731	0.2866	1.12	0.338

site.Seed shape	1	0.1515	0.1515	0.59	0.447
weed_frequency.Seed shape	2	0.3498	0.1749	0.68	0.511
site.weed_frequency.Seed shape	2	0.1497	0.0749	0.29	0.748
Residual	33	8.4292	0.2554		
Total	47	20.0413			

Variate: Summer proline (umol/gdw)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.7546	0.2515	0.39	
Rep.*Units* stratum					
planting_site	1	9.0882	9.0882	14.08	<.001
weeding_frequency	2	50.6123	25.3062	39.20	<.001
Seed shape	1	0.5766	0.5766	0.89	0.351
planting_site.weeding_frequency	2	2.2670	1.1335	1.76	0.189
planting_site.Seed shape	1	0.2130	0.2130	0.33	0.570
weeding_frequency.Seed shape	2	0.4294	0.2147	0.33	0.719
planting_site.weeding_frequency.Seed shape	2	0.9254	0.4627	0.72	0.496
Residual	33	21.3050	0.6456		
Total	47	86.1716			

CV=26.7%

Variate: Summer protein (mg/g)

Variate:summer mg/g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	3	0.28785	0.09595	0.99	
rep.*Units* stratum					

site	1	0.14307	0.14307	1.48	0.232
Weeding_frequency	2	15.07476	7.53738	77.95	<.001
Seed shape	1	0.00553	0.00553	0.06	0.812
site.Weeding_frequency	2	0.26924	0.13462	1.39	0.263
site.Seed shape	1	0.09832	0.09832	1.02	0.321
Weeding_frequency.Seed shape	2	0.48231	0.24116	2.49	0.098
site.Weeding_frequency.Seed shape	2	0.00703	0.00351	0.04	0.964
Residual	33	3.19093	0.09669		

Total 47 19.55905

CV=15%

Variate: Summer fructose

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	3		0.24699	0.08233	1.59	
Rep.*Units* stratum						
site	1		0.11238	0.11238	2.17	0.155
weeding_frequency	2		4.23605	2.11803	40.82	<.001
Seed shape	1		0.03153	0.03153	0.61	0.444
site.weeding_frequency	2		0.74533	0.37266	7.18	0.004
site.Seed shape	1		0.15223	0.15223	2.93	0.101
weeding_frequency.Seed shape	2		0.32354	0.16177	3.12	0.064
site.weeding_frequency.Seed shape	2		0.07776	0.03888	0.75	0.484
Residual	22	(11)	1.14160	0.05189		
Total	36	(11)	5.30460			

CV=25.5%

Variate: Summer glucose

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	3		0.06074	0.02025	1.06	
Rep.*Units* stratum						
site	1		0.04005	0.04005	2.10	0.158
weeding_frequency	2		4.89237	2.44618	128.34	<.001
Seed shape	1		0.02274	0.02274	1.19	0.284
site.weeding_frequency	2		0.11301	0.05650	2.96	0.068
site.Seed shape	1		0.05168	0.05168	2.71	0.111
weeding_frequency.Seed shape	2		0.00165	0.00082	0.04	0.958
Site. Weeding_frequency.Seed shape	2		0.07439	0.03719	1.95	0.161
Residual	28	(5)	0.53368	0.01906		

Total 42 (5) 4.99322

CV=15.6%

Variate: Summer sucrose

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.40621	0.13540	2.28	
Rep.*Units* stratum					
Site	1	0.35735	0.35735	6.01	0.020
weeding_frequency	2	5.89422	2.94711	49.58	<.001
Seed shape	1	0.00463	0.00463	0.08	0.782
Site. Weeding_frequency	2	0.10515	0.05257	0.88	0.422
Site. Seed shape	1	0.02006	0.02006	0.34	0.565
weeding_frequency.Seed shape	2	0.12334	0.06167	1.04	0.366
Site. Weeding_frequency.Seed shape	2	0.03340	0.01670	0.28	0.757

Residual	33		1.96144	0.05944		
Total	47		8.90581			

CV=22.8%

Variate: Winter fructose

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	3		0.074580	0.024860	7.76	
Rep.*Units* stratum						
weeding_frequency	2		2.566106	1.283053	400.25	<.001
Seed shape	1		0.011633	0.011633	3.63	0.086
weeding_frequency.Seed shape	2		0.009908	0.004954	1.55	0.260
Residual	10	(5)	0.032056	0.003206		
Total	18	(5)	1.976326			

CV=8.9%

Variate: Winter glucose

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	3		0.01807	0.00602	0.59	
Rep.*Units* stratum						
weeding_frequency	2		1.38254	0.69127	67.71	<.001
Seed shape	1		0.00491	0.00491	0.48	0.500
weeding_frequency.Seed shape	2		0.00212	0.00106	0.10	0.902
Residual	13	(2)	0.13271	0.01021		

Total	21	(2)	1.42636

CV=15.2%

Variate: Winter sucrose

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.01461	0.00487	0.38	
Rep.*Units* stratum					
Weeding frequency	2	2.37546	1.18773	92.40	<.001
Seed shape	1	0.00511	0.00511	0.40	0.538
weeding_frequency.Seed shape					
	2	0.02101	0.01051	0.82	0.460
Residual	15	0.19282	0.01285		
Total	23	2.60900			

CV=12.8%

Variate: Winter starch (mg/g)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
rep stratum	3		31.578	10.526	3.43	
rep.*Units* stratum						
Weed frequency	2		230.910	115.455	37.62	<.001
Seed shape	1		0.631	0.631	0.21	0.662
weed_frequency.Seed shape	1	(1)	0.859	0.859	0.28	0.611
Residual	8	(7)	24.553	3.069		
Total	15	(8)	173.915			

CV=19%

Variate: Winter proline (umol/gdw)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	3		10.054	3.351	1.08	
Rep.*Units* stratum						
Planting site	1		4.268	4.268	1.37	0.250
Weeding frequency	2		336.603	168.302	54.14	<.001
Seed shape	1		5.584	5.584	1.80	0.190
planting_site.weeding_frequency	2		32.142	16.071	5.17	0.011
planting_site.Seed shape	1		26.818	26.818	8.63	0.006
weeding_frequency.Seed shape	2		2.654	1.327	0.43	0.656
planting_site.weeding_frequency.Seed shape	2		18.106	9.053	2.91	0.069
Residual	32	(1)	99.474	3.109		

Total 46 (1) 533.019

CV=29.5%

Variate:Winter protein

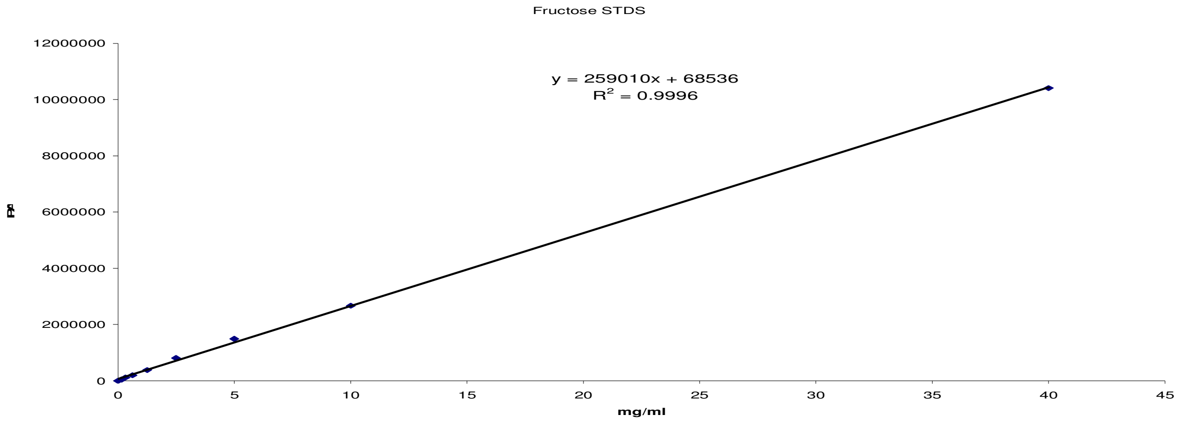
Variate: mg_g

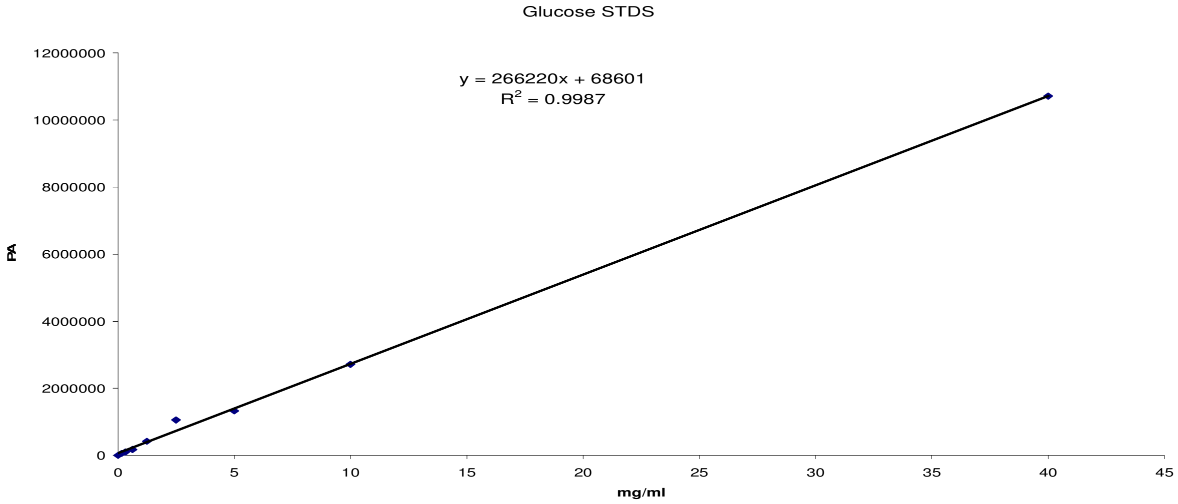
Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
rep stratum	3		0.10371	0.03457	1.61	
rep.*Units* stratum						
weeding	2		12.87668	6.43834	299.66	<.001
Seed shape	1		0.02571	0.02571	1.20	0.310
weeding.Seed shape	1	(1)	0.06251	0.06251	2.91	0.132
Residual	7	(8)	0.15040	0.02149		

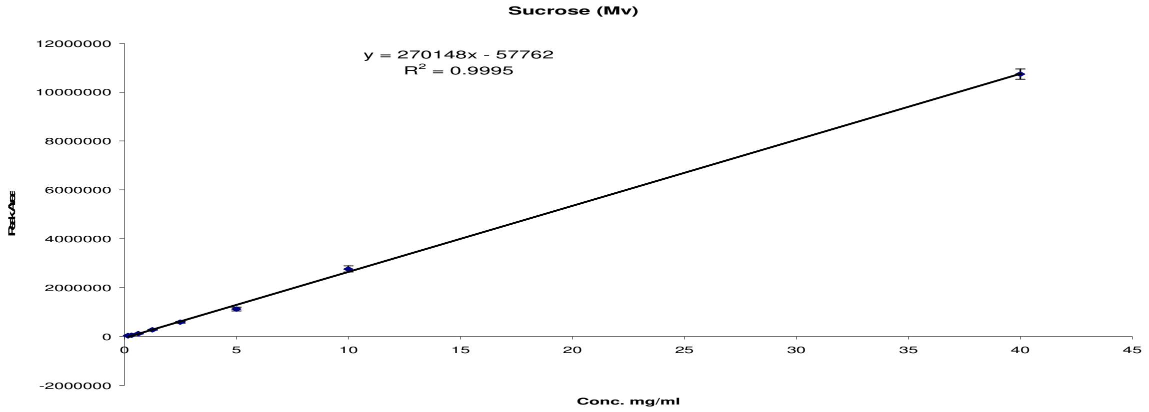
Total 14 (9) 4.85919

CV=6.5%

Calibration curves





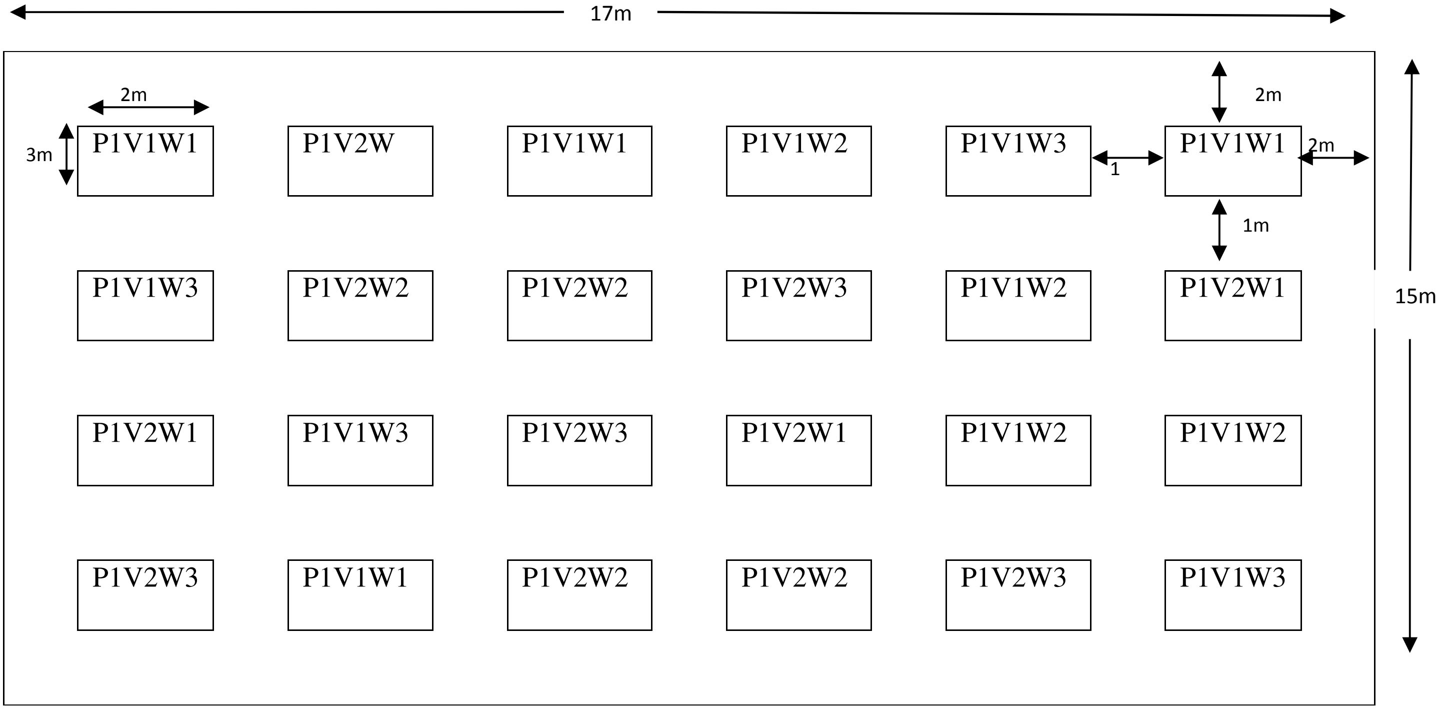


Appendix 4: Field Trial plots for summer and winter planting

Treatment factors: Planting date (P1, P2), Seed shape (V1, V2), weeding method (W1, W2, W3) **NB:** The same measurement will be used as in Planting date 1(P1) in Planting date 2 (P2)

V1= SC701 Round, V2 = SC701 Flat, W1 = no weeding, W2 = Single weeding, W3 = Double weeding,

First Planting Season

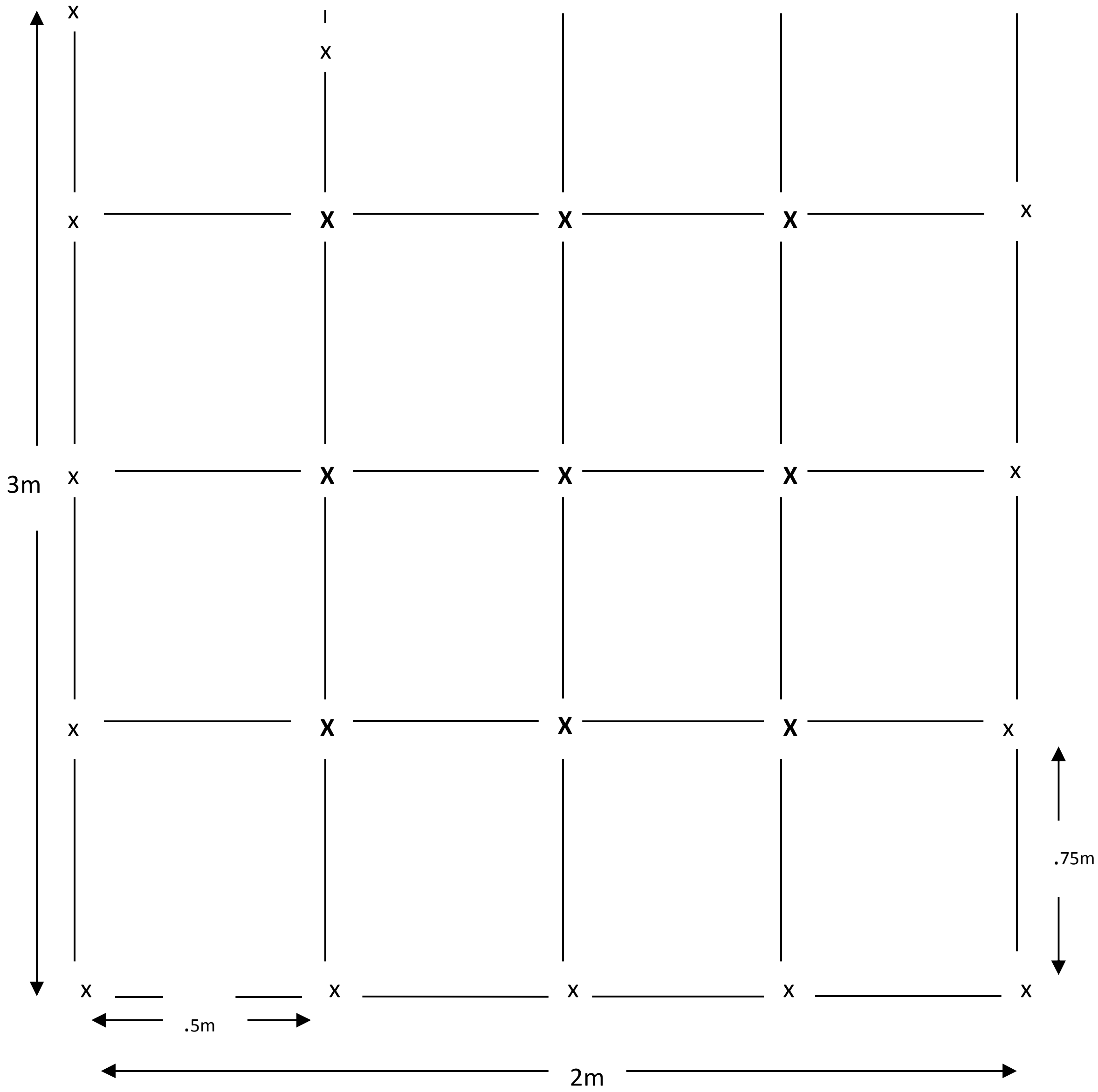


P1V1W1	P1V2W	P1V1W1	P1V1W2	P1V1W3	P1V1W1
P1V1W3	P1V2W2	P1V2W2	P1V2W3	P1V1W2	P1V2W1
P1V2W1	P1V1W3	P1V2W3	P1V2W1	P1V1W2	P1V1W2
P1V2W3	P1V1W1	P1V2W2	P1V2W2	P1V2W3	P1V1W3

Second planting season

P2V2W2	P2V1W3	P2V1W2	P2V2W3	P2V1W3	P2V1W2
P2V2W1	P2V2W3	P2V2W1	P2V2W2	P2V2W3	P2V1W2
P2V1W1	P2V1W3	P2V1W2	P2V2W1	P2V1W1	P2V1W3
P2V1W1	P2V2W1	P2V2W3	P2V2W3	P2V1W1	P2V2W2

Individual Plot Layout



Key:

x= non-experimental plant

X= experimental plant