EMERGENCE RESPONSE OF SUNFLOWER CULTIVARS (*Helianthus annuus* L.) TO PLANTING TECHNIQUES AND SOIL FACTORS

by

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ABSTRACT

South Africa mainly produces oil seed sunflowers of which 86% is produced in the Free State and North West provinces which are known for their sandy soils. Temperatures can rise to 42°C in these soils when planting commences during November to January. These conditions, in combination with other factors such as planting date and planting depth, soil type, different cultivars, and seedling vigour, can influence the emergence rate of sunflower seedlings. This will cause uneven stand which could affect the yield negatively.

In an attempt to evaluate the influence of soil factors and planting techniques on sunflower emergence, three experiments were conducted in the greenhouse at the Department of Soil, Crop and Climate Sciences of the University of the Free State. These experiments evaluated the effect of seed size, planting techniques, and soil factors, and high soil temperatures on the emergence rate of selected sunflower cultivars.

Three seed sizes (seed size one to three) of three cultivars (PAN 7049, PAN 7057, and PAN 7063) were planted at two planting depths (25 and 50 mm respectively) during three planting dates (September 2010, November 2010, and February 2011) to determine the influence on the emergence rate of seedlings. It was found that a smaller seed size, such as seed size three, emerged faster than larger seeds, seed size one.

The influence of two planting depths (25 and 50 mm) during the previously mentioned planting dates with two soil types (Bainsvlei and Tukulu) on the emergence of sunflower seedlings was also tested. Cultivar emergence was faster at 25 than at 50 mm. It was also observed that the emergence rate was faster during February 2011 than during September and November 2010. Although the emergence was faster during February 2011, above ground growth (plant height and dry weight) was greater during November 2010 than during September 2010 and February 2011.

The influence of four soil temperatures (35, 40, 45, and 50°C respectively) on the emergence of sunflower cultivars was tested. An under floor heating wire (23 kW) was attached to a galvanised metal grid and was used to simulate day and night temperatures in the top soil. The grid and seed were placed at a depth of 25 mm (planting depth). Emergence index declined gradually from 35 to 45°C, but a rapid decline in emergence index was observed from 45 to 50°C.

Emergence can be measured or calculated as an emergence index. Emergence is determined as the moment that the seedling is visible above the ground and different formulas exist to determine the emergence. Experiments differ from one another and therefore different emergence index models were developed to accommodate the experiment methods or crop that was used. It can therefore be concluded that differences in emergence exist between cultivars. It is also necessary for producers to acknowledge that soil factors and planting techniques play a vital role during planting until the seedling emerge.

Keywords: Sunflower emergence, soil temperature, seedling growth, seed size, planting depth, planting date

OPSOMMING

Produksie van sonneblomme in Suid-Afrika is meestal vir olie. Ongeveer 86% word in die Vrystaat en Noord-Wes provinsies, wat ook vir sanderige grond bekend staan, geproduseer. In dié grond kan temperature van November tot Januarie bo 42°C tydens die plantseisoen styg. Hierdie toestande, in kombinasie met ander faktore soos plantdatum, -tyd, grondtipe, kultivarverskille en saailing groeikragtigheid, kan die opkomstempo van sonneblomsaailinge beïnvloed. Dit kan lei tot oneweredige plantestand wat opbrengs nadelig kan beïnvloed.

Ten einde die invloed van grondfaktore en planttegnieke op die opkoms van sonneblomme te evalueer, is drie eksperimente in die glashuise van Departement Grond, Gewas en Klimaatwetenskappe van die Universiteit van die Vrystaat uitgevoer. Hierdie eksperimente het die invloed van saadgrootte, planttegnieke en grondfaktore, asook hoë grondtemperature op die opkomstempo van geselekteerde sonneblomkultivars getoets.

Drie saadgroottes (saadgrootte een tot drie) van drie kultivars (PAN 7049, PAN 7057 en PAN 7063) is op twee plantdieptes (25 en 50 mm) geplant op drie plantdatums (September 2010, November 2010 en Februarie 2011) om die invloed op die opkomstempo van saailinge te bepaal. Daar is gevind dat kleiner saadgroottes soos saadgrootte drie vinniger ontkiem as groter sade (saadgrootte een).

Die invloed van twee plantdieptes (25 en 50 mm) by die drie plantdatums op twee grondtipes (Bainsvlei en Tukulu) op die opkoms van sonneblomsaailinge is ook bepaal. Kultivaropkoms was vinniger by ‘n plantdiepte van 25 as by 50 mm. Opkomstempo was ook vinniger gedurende Februarie 2011 as gedurende September en November 2010. Alhoewel die opkomstempo tydens Februarie 2011 vinniger was, was die bogrondse groei van plante (planthoogte en droë massa) egter beter gedurende November 2010 as die ander plantdatums.

Laastens is die invloed van vier grondtemperature (35, 40, 45, en 50°C) op die opkoms van sonneblomkultivars bepaal. ‘n Ondergrondse verhittingsdraad (23 kW) is aan ‘n gegalvaniseerde metaalrooster geheg. Die verhittingseenheid is gebruik om dag- en nagtemperature in die bogrond te simuleer. Die rooster en saad is op ‘n diepte van 25 mm (plantdiepte) geplaas. Opkoms-indeks het geleidelik afgeneem vanaf 35 tot 45°C, maar ‘n drastiese afname was sigbaar in die opkoms-indeks vanaf 45 to 50°C.

Opkoms kan gemeet of berereken word as ‘n opkoms-indeks. Opkoms word bepaal wanneer die saailing sigbaar is bokant die grond. Verskillende formules bestaan om hierdie opkoms te bepaal. Eksperimente verskil en daarom is verskillende opkoms-indeks modelle ontwikkel om ‘n eksperimentele metode of gewas te akkomodeer. Uit hierdie eksperimente is dit duidelik dat opkomsverskille tussen kultivars bestaan. Grondtemperature kan opkoms beïnvloed en meer navorsing is noodsaaklik in Suid-Afrika waar hoë grondtemperature algemeen voorkom tydens die plantseisoen. Produsente moet ook kennis neem dat grondfaktore en planttegnieke ‘n belangrike rol speel vanaf plant tot opkoms.

Kernwoorde: Sonneblomopkoms, grondtemperature, saailinggroei, saadgrootte, plantdiepte, plantdatum

CHAPTER 1

INTRODUCTION

The sunflower (*Helianthus annuus* L.) is a member of the Asteraceae family native to North America and is cultivated over large areas of the United States of America (Schneiter, 1994; Weiss, 2000). Sunflower seeds were used by native Americans as a food source and today sunflower is an important oilseed crop from which edible oil rich in mono-unsaturated fats is extracted (De la Vega & Hall, 2002; Al-Chaarani *et al*., 2005; Chen *et al*., 2009). Sunflower is considered a widely adaptable crop and grows successfully over a wide range of geographical areas and under a wide range of environmental conditions (De la Vega & Hall, 2002). Cultivated sunflower is one of 67 species occurring in the genus *Helianthus* (Schneiter, 1994). The first commercial hybrid sunflower was introduced in 1972 and its introduction resulted in increased yields of up to 25%. Genetic progress also led to the introduction of short-stemmed, high-yielding cultivars allowing for more efficient mechanised cropping, making sunflower a major international oilseed (Schneiter, 1994).

There are two main types of sunflower, namely sunflowers for oilseed production, and the non-oilseed types for bird food and domestic markets. Oilseed sunflowers contain approximately 20% protein and 38-50% oil (Schneiter, 1994). South Africa mainly produces oilseed sunflower with a total production of 894 000 t y^{-1} (1.39 t ha^{-1}) (Department of Agriculture, Forestry and Fisheries, 2012). The Free State (50%) and North West (36%) provinces combined are responsible for 86% of the total South African sunflower production (Department of Agriculture, Forestry and Fisheries, 2012). Both provinces are known for their sandy soil types, especially the western Free State and larger parts of the North West province. In these sandy soils temperatures frequently rise above the critical level of ±43°C when planting commences in the months of November to mid-January (Nel, 1998a & 1998b). These conditions and a combination of other factors culminate in poor emergence, and ultimately lead to poor stand.

Crop stand depends on crop establishment which consists of three stages, namely germination, seedling growth below soil surface, and emergence. Germination of seeds can only be observed when seedlings emerge through the soil surface. After germination young seedlings are exposed to various factors when the seedlings grow through the soil until it reaches the soil surface. Factors affecting this stage include planting techniques, texture of top soil, planting depth, soil temperature, high water and low oxygen content in the seed zone, fertilisation, chemical seed treatment, and herbicides. Emergence and emergence rate are important for crop establishment (final stand) and may affect the success of the crop and even increase yield by as much as 20%. Unfortunately, sunflower germinability is wrongly accused for poor emergence. This may be attributed to the overlap between germination and emergence. Notwithstanding the fact that germinability could impact emergence, emergence is greatly influenced by growth vigour of the seedling (Unger, 1984; Katerji *et al*., 1994; Helms *et al*., 1996; Soltani *et al*., 2006; Berti & Johnson, 2008). The rapid, complete, and uniform emergence of sunflower will reduce the time from planting to complete ground cover and is a prerequisite for high yielding conditions (Soltani *et al*., 2006).

Factors affecting high yielding conditions through seedling emergence include temperature, crust thickness, and strength, and these are all dependent on soil water content (Unger, 1984). It is known that initial soil water content may be sufficient for imbibition, but may be insufficient for complete germination or seedling emergence (Helms *et al.*, 1996 & 1997). Seed characteristics of sunflower are also a factor that can influence emergence. These include 100-seed weight (seed size) and oil content. An increase in seed weight will decrease oil content in seeds and this indicates that seed size is more important than oil content for emergence of sunflowers (Ahmad, 2001).

Through experience and research it is known that soil temperature is instrumental to sunflower emergence (Anonymous, 1995). Soil temperature in the planting zone is also dependent on planting depth and soil texture. Therefore, the objectives of this study are to:

- determine and evaluate the effect of planting depth, planting date (for varying soil temperatures), soil texture, and seed size on the emergence of commercial sunflower cultivars,
- to determine the effect of varying soil temperatures in the seeding zone on root growth and emergence of selected cultivars.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Sunflower seedling establishment can be described as the most critical phase for the plant and ultimately optimum plant population density. During this phase seeds germinate, roots develop, the hypocotyls lengthen and the young seedlings emerge through the soil surface. Many factors, such as planting date and depth, seed size, soil temperature, soil water content and soil texture can influence sunflower establishment. A delay in sunflower establishment can ultimately cause lower yields.

Temperature is one environmental variable that plays a vital role in all production practises. Planting date and planting depth, as well as agronomic management factors, are dependent on soil temperature. Depending on climatic conditions and soil type, early planting dates usually correspond with cooler soil temperatures that may delay emergence rates, but can also be favourable for soil moisture content (Anonymous, 1995; Barros et al., 2004). Low soil temperatures (≤10°C) decrease evaporation from the soil which is advantageous for germination, while high temperatures can lead to faster evaporation. Therefore, stand establishment can be affected by high soil temperatures (>45°C) and low soil moisture (≤0.07 kg kg-1). The ideal soil temperature for germination of sunflower is between 20 and 30°C (Corbineau et al., 1988; Gay et al., 1991; Villalobos et al., 1996; Helms et al., 1997; De Villiers, 2007). An increase in the planting depth (deeper than 50 mm) will decrease sunflower emergence rate (Du Toit, 1981). Knowing this, the question arises. Is this applicable to all sunflower cultivars?

Seed size can also influence emergence rate of sunflowers, and information regarding the latest cultivars is scarce or unavailable. Smaller seeds absorb water more efficiently than larger seeds (Hernández and Orioli, 1985). However, large seeds contain more food reserves in the cotyledons and therefore these seeds may develop into stronger seedlings (Hernández and Orioli, 1985; Longer *et al*., 1986; Farahani *et al*., 2011).

Encrustation or compaction can further add to poor emergence of sunflowers. This can be explained by low oxygen levels and high crust strength that cause seedlings to snap at the hook of the hypocotyls (Rathore *et al*., 1981; Massingue, 2002; Hyatt *et al*., 2007). A combination of all practices and environmental factors can lead to poor emergence resulting in poor crop stand, reduced yields or replanting.

2.2 Phenology: Emphasis on seedling establishment

Growth can be described as an increase in plant size, such as leaf area, plant height and dry mass in response to environmental conditions (Anonymous, 1995). The environment and genetic background determine the total time of development of sunflower seedlings. Development can be described as the progression of growth stages from early stages to maturity (Scneiter, 1994; Anonymous, 1995; Connor & Hall, 1997; Anonymous, 2013). Schneiter & Miller (1981) developed a simple classification system for the growth stages of sunflowers. It is divided into two main phases, namely the vegetative and reproductive stages. The vegetative stage consists of two sub phases namely i) germination and seedling development (emergence) and ii) leaf development (Anonymous, 1995).

During germination the seeds absorb water from the soil (imbibition) and the germination process end when the radicle becomes visible. Three factors affect this stage, namely the permeability of the seed coat to water, available water in the soil, and the composition of the seed (Mayer & Poljakoff-Mayber, 1975). In order for germination to occur an optimum soil temperature range (20-30°C) as well as adequate water in the soil profile (10-50 mm), especially in the germinating zone, is necessary (Corbineau *et al*., 1988; Gay *et al*., 1991; Villalobos *et al.*, 1996; De Villiers, 2007).

The radicle will protrude and lengthen to form the primary root (Figures 2.1a & b). Sunflowers are known to develop a tap root system that can penetrate the soil up to 2 m deep. Lateral roots (Figures 2.1c & f) will also develop in the top 100 to 150 mm of soil during the early stages of plant development. Lateral roots can develop further in the top 300mm of the soil profile (Knowles, 1978; Anonymous, 1995). Primary roots grow optimally at soil temperatures of 20 to 30°C, while optimal lateral root growth occurs at a soil temperature of 25 to 30°C (Seiler, 1998). Sunflowers grow well in a variety of soils, but a well-drained soil with a high water capacity and neutral pH of 6.5 to 7.5 is best for cultivation. The clay percentage should preferably be less than 20% (Fanning, 1994; Anonymous, 2010).

With emergence of sunflower seedlings through the soil surface the cotyledons unfold to produce the first pair of true leaves in the shoot axis as seen in Figure 2.1d - f (Knowles, 1978). Emergence of sunflowers can be restricted by soil compaction or encrustation which causes seedlings to snap at the hypocotyl hook during severe stress (Rathore *et al.*, 1981; Anonymous, 1995; Hyatt *et al., 2*007). The last phase of germination and seedling development (emergence) consists of the development and growth of the first true leaves (Figure 2.2a). The length of the first true leaves will be the same as the cotyledons during this phase (Anonymous, 1995).

The leaf development stage commences when the first true leaves unfold and lasts until the budding stage commences (Figures 2.2a & b). Leaf senescence may be visible at the bottom of the stem as the plant mature. To determine the proper stage leaf scars must be counted (Schneiter & Miller, 1981; Anonymous, 1995; Anonymous, 1999).

During the reproductive stage sunflowers will start with bud formation and end with maturity (Figures 2.2b - f). The bud (sunflower head) enlongates more than 20 mm above the nearest leaf, followed by bracts opening. The ray flowers will be visible and this is the beginning of anthesis (Figure 2.2d). When anthesis is complete the ray flowers will wilt (Figure 2.2e). The bracts will become yellow and brown and the ray flowers will turn brown and start to dry (Figures 2.1e & f). This phase is known as pysiological maturity of sunflowers (Schneiter & Miller, 1981; Anonymous, 1995; Anonymous, 1999).

The identification of the growth stages of sunflowers is essential. This helps with knowledge and understanding of the sunflower plant during stress conditions (Connor & Hall, 1997).

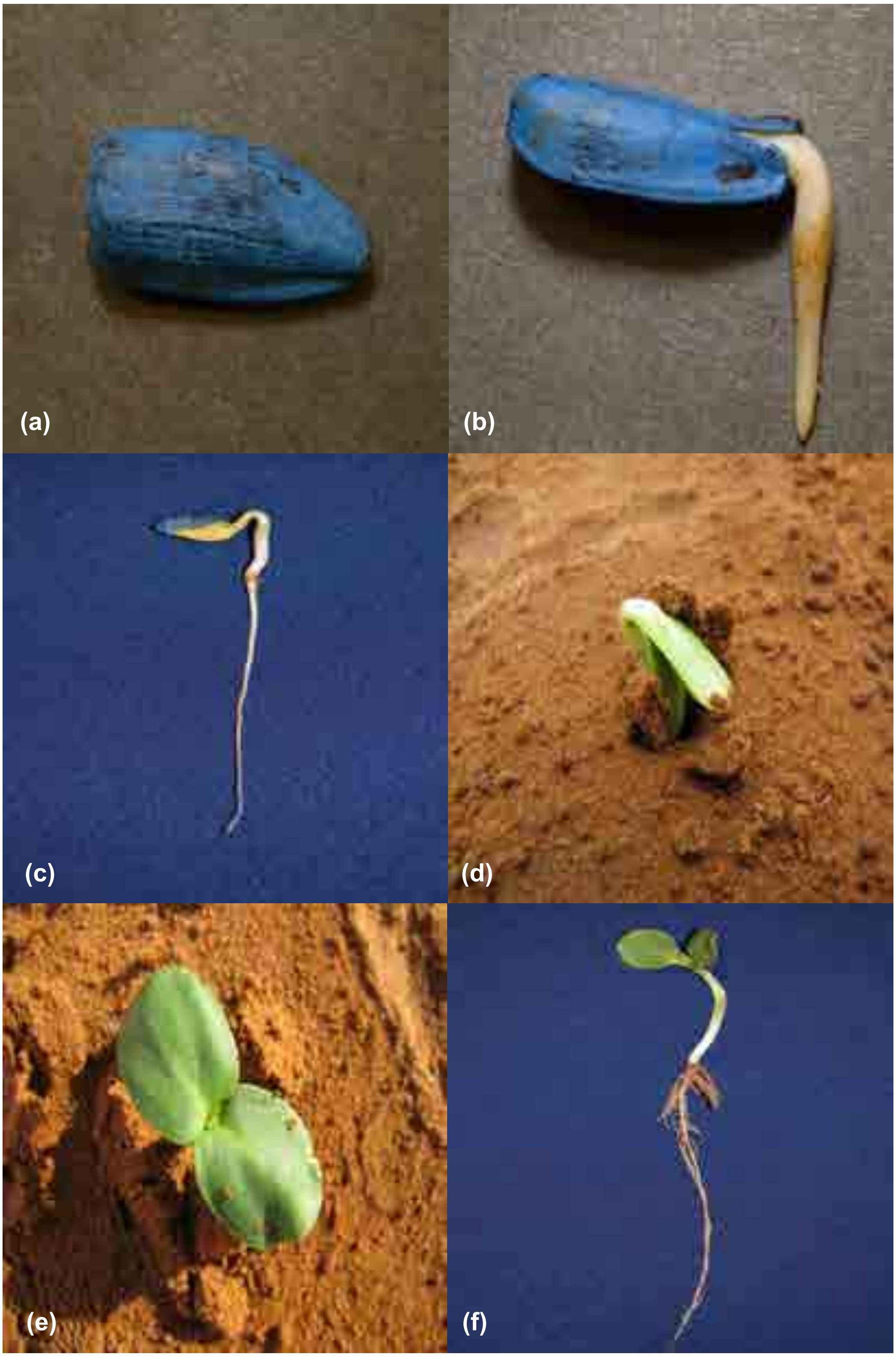


Figure 2.1 Early seedling growth and emergence – (a) germination, (b) radicle visible, (c) growth below soil surface, (d) protruding cotyledons, (e) emerged seedling, (f) seedling above and below soil surface (Photos: L. Henning, 2012 & 2013).

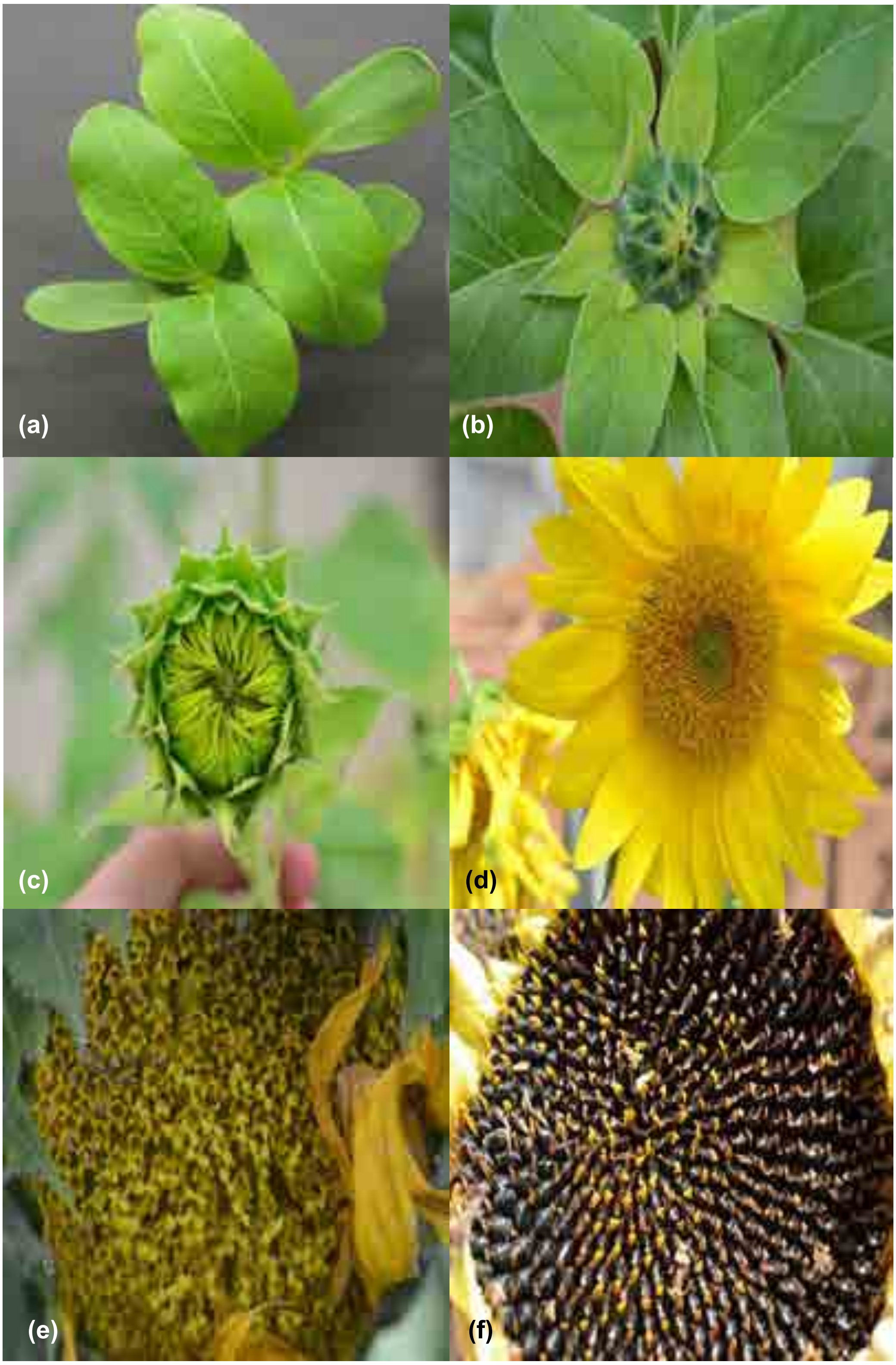


Figure 2.2 Development of sunflower from vegetative to reproductive stages – (a) Leaf development, (b) Beginning of reproductive stage (bud formation), (c) Inflorescence starting to open, (d) Beginning of anthesis, (e) Anthesis complete, (f) Physiological maturity (Photos: L. Henning, 2012 & 2013).

2.3 Planting Techniques and Emergence

2.3.1 Planting date

Sunflowers can be planted over a wide range of planting dates since sunflower has a shorter growth season compared to other agronomic crops such as maize (Putnam *et al*., 1990; Coetzee, 2010; Anonymous, 2012). The planting date generally stretches from the beginning of November to the end of December in the eastern areas of South Africa. In the western areas early planting can commence as early as the last week in September, but late plantings do occur as late as the last week in January (Anonymous, 1999; Anonymous, 2012). All principles regarding the planting time, such as soil water content, soil temperature, rainfall distribution, and crop temperature requirements must be considered (Anonymous, 1999; Barros *et al.,* 2004; De Villiers, 2007). High soil temperatures (>40°C) during planting in sandy soil can often lead to poor germination and emergence of sunflowers. Planting should therefore occur earlier in the season to reduce this risk (Nel, 2003; Anonymous, 2010).

Lawal *et al*. (2011) state that vegetative parameters such as plant height, number of leaves, and stem girth of sunflowers during late planting were significantly higher than that of sunflowers planted earlier. This can be explained by the adequate moisture content in the soil with late planting. The soil moisture was favourable for root growth during emergence and the vegetative stages, resulting in a good growth response to nutrient absorption through roots. However, this growth response was not evident in seed yield, which had the opposite response. This phenomenon was also reported by Soriano *et al*. (2004). Aerial biomass of sunflowers was also higher with early planting than the biomass of a late planting. According to Soriano *et al.* (2004) higher yields were recorded with early plantings in 1989 and 1996 than with late plantings. Both studies indicated that, when rainfall subsides at the end of the season, adequate moisture is no longer available during the reproduction stages of the plant which influence seed production negatively. Sunflower planted late in the season produced smaller heads with tiny seeds, and the seeds in the centre were hollow (Soriano *et al.*, 2004; Lawal *et al.*, 2011).

In contrast with above findings, oil content and yield can be maximised with an early planting date. The disadvantage of low soil temperature and delayed emergence is compensated for by the high probability of more favourable moisture conditions with a late planting depth (Miller *et al*., 1984; Barros *et al*., 2004; Petcu *et al*., 2010).

According to Du Toit (1981) sunflower seed germinates best during October at average soil temperatures of 22-23°C, and at planting depth ranging from 25-10 mm. Although germination was best during October, Du Toit (1981) also proved that sunflower stand was greater during September than November (with average temperatures of 30°C). It is therefore evident that favourable soil temperatures during October will not necessarily increase the emergence or stand of sunflowers. This can only prove that the best possible germination temperature range for sunflower seeds is at 22-23°C. Higher temperatures (>30°C) during November are more likely to reduce emergence of seedlings than during the cooler temperatures of September (Du Toit, 1981). It can therefore be concluded that planting date depends on soil temperature.

2.3.2 Planting depth

The ideal sunflower planting depth, according to Berglund (1994) and Weiss (2000) is between 30 and 80 mm in moist soil. However, a planting depth of 25 to 50 mm is preferable in South Africa (Anonymous, 1995). It is critical that the soil stays moist during the germination period. Dry top- and moist subsoil is a common combination for optimum planting dates in dry land conditions (Weiss, 2000). In warm (25 to 30°C) sandy soils sunflowers can emerge from a depth of 80mm, but emergence is usually delayed under these environmental conditions (Berglund, 1994).

Du Toit (1981) states that the ideal germination and emergence of sunflowers will take place at a depth of 25 to 50 mm. This was tested under field and controlled conditions and deeper planting depths influenced emergence rates negatively. The emergence percentage was 97% at 25 mm depth and 68% at 75 mm depths (Du Toit, 1981). Days from plant to emergence may also increase with an increase in planting depth. An increase in planting depth above 50 mm did not only affect seedling emergence negatively, but seedlings also emerged unevenly (Du Toit, 1981).

Blamey, Zollinger & Schneiter (1997) find that emergence decreases from 88% to 83% as planting depth increased from 25 to 102 mm. Du Toit (1981) states that, with an increase in planting depth, the days to emergence also increased. Sunflowers planted at a depth of 30 mm can emerge and flower 4 days earlier than sunflower seeds planted at 80 mm. A decrease in emergence, root and shoot length, and dry matter was evident as the depth increased with 30 mm increments from 30 to 150 mm (Robinson, 1978). It was also found that the planting depth should be deeper in sandy soils than fine textured (clay) soils. At a depth of 30, 40, 50 and 70 mm the emergence was as follow: 85, 95, 92, and 84%. This indicates that a 40 mm planting depth is ideal for sandy soils (Robinson, 1978). Mohammed *et al.,* (1984) found that a planting depth of 75 mm yielded a higher stand than 25 and 50 mm planting depths in sandy loam soil. Seeds at a shallow (25 mm) planting depth can emerge faster than seeds at a deeper (>50 mm) planting depth. This is due to the fact that the seed is closer to the soil surface. However, air temperature strongly affects the soil temperature near the surface during the day (Robinson, 1978). This should be kept in mind when deciding on a planting date. The soil temperature and moisture can determine the ideal planting depth at a specific planting date. Deeper planting depths (>50 mm) can mean an extended period with adequate soil moisture, but it is not necessarily the best depth (Nel, 2010).

2.3.3 Seed size

Sunflower seed is called a fruit or achene. The fruit consists of the seed or kernel inside the pericarp or hull (Figure 2.3). The largest seeds are positioned on the outer perimeter of the sunflower head and the smallest seeds at the centre. The difference between large and small achenes is visible in the hulls. Large achenes have thick hulls, while small achenes have thin hulls. Large achenes are, therefore, not well filled, while small achenes are tightly fitted inside the hulls (Knowles, 1978).

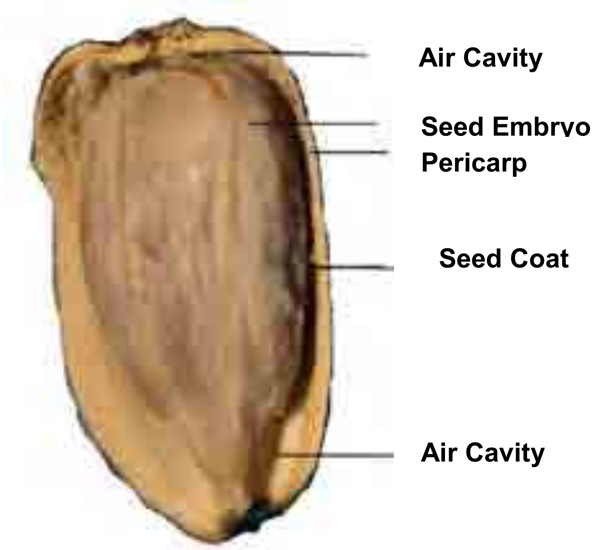


Figure 2.3 Section of an achene showing the pericarp or hull and seed of sunflower (Photo: L. Henning, 2013).

Seed emergence depends on physiological reactions that take place in the seed after imbibition. Imbibition is the ability of seeds to absorb water from the soil, and this process can also be structure related. During germination the survival and growth of the seedlings are also dependent on the food reserve that is stored in the seed (Hernández and Orioli, 1985; Longer *et al.*, 1986; Farahani *et al.*, 2011). Seedlings from larger seeds generate a greater emergence force than those from small seeds. Development of roots and shoots from these large seeds is better than those from small seeds (Longer *et al.*, 1986). However, small seeds have smaller cavities inside the hull, and therefore the achene and pericarp are in close contact. This will lead to more efficient water absorption through the hull (Hernández and Orioli, 1985). On the other hand, Farahani *et al*. (2011) concluded that germination percentage decreases with an increase in seed size and that seedling length increases with an increase in seed size.

2.4 Soil Factors and emergence

2.4.1 Temperature

Temperature is an environmental variable that strongly influences crop growth and development (Villalobos & Ritchie, 1992; Chimenti *et al.*, 2001; Fayyaz-Ul-Hassan & Mumtaz, 2005). Crops are grown in regions based on the tolerance to temperature and cannot be manipulated in field conditions. This causes many problems in the cultivation of sunflower (Chimenti *et al.*, 2001). Sunflowers are adapted to a wide range of temperatures, especially after emergence. Soil temperature is extremely important during germination and acceptable sunflower germination occurs at temperatures between 5 and 40°C (Gay *et al*., 1991). The optimum range of temperature for germination is between 20 and 30°C (Corbineau *et al*., 1988; Gay *et al*., 1991; Villalobos *et al*., 1996; De Villiers, 2007). During germination seeds absorb water (imbibition) and physiological processes are initiated. During these processes energy is produced and used by the embryo to develop into a seedling (Corbineau *et al*., 1988; Hopkins & Hüner, 2004; Mei & Song, 2008).

Temperatures of 45°C and higher during imbibition can cause leakage of solutes from cells indicating damage to cell membranes of seeds. Stress periods of 48 hours and more during imbibition can cause the enzyme malate dehydrogenase to leak with solutes from seeds. Leakage of this enzyme is associated with the loss of seed viability (Givelberg *et al*., 1984).

Germination will not be affected when seeds are subjected to high temperatures (>45°C) after an incubated period of 16 hours at 25°C, because the imbibition process is completed (Corbineau *et al*., 1988). High temperatures of 45°C or more often induces thermo dormancy or secondary dormancy, causing seedlings to grow slowly or abnormally. Root growth, however, is more sensitive to thermo dormancy than growth of the hypocotyl. When the pre-incubation period is extended at 45°C, seeds lose the ability to germinate at 25°C. Seedling growth is slowed down and becomes abnormal (Corbineau *et al*., 1988).

Induction of thermo dormancy at high temperatures is not only associated with ethylene biosynthesis, but also with gene expression and induction of heat shock proteins (Corbineau *et al*., 1988). Ethylene biosynthesis is primarily a response to stress and can occur in any plant organ including roots, stems, leaves, bulbs, tubers, and seeds (Hopkins & Hüner, 2004). Ethylene production can break this secondary dormancy, and the induction of secondary dormancy is associated with the inability of seeds to produce ethylene (Corbineau *et al*., 1988). The optimum temperature for the production of ethylene is 30°C with a peak production at 35 to 37.5°C. Temperatures above this level cause a decline in ethylene production and at 45°C and above no ethylene production will be detected (Yu *et al.,* 1980; Field, 1981). At these high temperatures the ethylene synthesising system is not destroyed, but temporarily suppressed. Recovery of the ethylene synthesising system was detected in experiments where leaf tissue was returned to temperatures of 25°C. Peak production of ethylene at temperatures of 35 to 37.5°C can restore membrane permeability (Field, 1981). Studies show that ethylene's precursor, ACC (1-aminocyclopropane-1-carboxylic acid), will increase at temperatures of 25 to 40°C, even though ethylene production decrease at 35°C (Yu *et al.,* 1980). Conversion of ACC to ethylene is inhibited at temperatures of 42.5°C and higher. This is an indication that the conversion of ACC to ethylene is more sensitive to high temperatures than the synthesis of ACC itself (Yu *et al.,* 1980; Horiuchi & Imaseki, 1986). These findings concur with that of Nel (1998b) where temperatures that exceeded 44°C also caused a decrease in seed vigour, leading to poor emergence.

Sandy soils can reach higher temperatures than soils with high clay contents (De Villiers, 2007). This is due to less clay, resulting in a decrease in water holding capacity, which in turn affects the heat conductivity of soil. With the exception of the surface soil layer (0 to ±50 mm) soil temperature is usually lower than air temperature during the growing season. Sadras *et al*. (1989) conclude that 95% of sunflower roots occur in the top 400 mm of soil. Roots are sensitive plant organs and are consequently less adaptive to extreme temperature changes or soil temperature fluctuations. The soil surface layer is warmer, and soil temperature fluctuations are common in this zone. This is also the zone where germination occurs, and the region where the hypocotyls have to grow through the soil to protrude the seed lobes. In the most upper soil layer root growth is generally non-existent under dryland conditions, especially in sandy soils. This is the result of the soil surface layer being desiccated. If sufficient soil water is available the root growth rate in the upper soil layer will exceed that of the root growth rate of horizontal growing roots in the subsoil layers (Nielsen, 1974). This will occur as a result of higher soil temperatures in the surface soil layer compared to the subsoil. When soil temperatures rise too high (>35°C), the surface soil will reduce metabolic activity and elongation of roots (McMichael & Quisenberry, 1993; Seiler, 1998).

Germination was tested at various temperatures (5, 10, 15, 20, 25, 30, 35 and 40°C) to determine at which temperature sunflowers germinate the best (Gay *et al.,* 1991). The optimum was established at 25°C. Low temperatures (5-10°C) and high temperatures (30-40°C) delayed germination and this decreased the percentage of germinated seeds. Lag time until onset of germination was increased and took 3 days at 5°C. At 20 and 25°C final germination was reached within 4 days after the experiment was commenced and increased emergence rates of sunflowers (Gay *et al.,* 1991). Khalifa *et al.* (2000) later tested the same experiment with six different hybrids. At 5°C the earliest germination was recorded at 12 days after planting. At 35, 37 and 40°C the first complete germination was determined at 17 hours after planting, indicating a correlation between temperature and germination rates. An increase in temperature will lead to an increase in germination percentage (Khalifa *et al*., 2000). High temperatures (>35°C), however, have the ability to decrease germination of sunflowers seeds with medium vigour levels (Albuquerque & De Carvalho, 2003). Root growth rate can increase with an increase in soil temperatures, but decreases when soil temperatures rise above the optimum range. Studies done by McMichael & Quisenberry, (1993) and Seiler (1998) indicate that optimum temperatures for primary and lateral root growth for sunflowers are between 20 and 30°C.

2.4.2 Water content

Available water in the soil profile for sunflower production is dependent on two sources, namely stored water in the soil, and rainfall during the season. Soil water content is essential for germination and development of crops. Germination is one of the critical stages in plant development, and water plays a vital role at this stage. Water uptake by seeds is one of the first processes which occur during germination, which is known as imbibition. This physical process involves the swelling of the seed's rehydrating seed tissue which activates the seed metabolism to trigger or commence germination (Mayer & Poljakoff-Mayber, 1975; Hopkins & Hüner, 2004).

Sunflowers' water usage has a positive relationship with yield (Anonymous, 1995). Sunflowers have the ability to adapt to low soil water content when compared to maize. Yields under high soil water content and favourable conditions will be lower than maize under the same conditions (Anonymous, 1995). If water stress occurs before flowering and through the seed development stage of sunflower, it will affect the yield of sunflowers (Anonymous, 1999; Weiss, 2000; Anonymous, 2013).

The interaction between soil water content and temperature can greatly influence emergence. The influence of temperature on emergence is a function of the soil water content in tests done on soya beans (Helms *et al.,* 1996). Helms *et al.* (1997) also tested sunflower at three soil water contents (0.05, 0.07 and 0.09 kg kg^{-1}) and three temperature regimes (17/8, 21/12 and 21/16°C) as stress treatments. After the treatments were applied soil water content was increased to 0.20 kg kg^{-1} to simulate rain. This was done to evaluate emergence for 6 days after the soil water content was increased. A temperature increase resulted in a decrease from 82 to 65% in the emergence of sunflowers for the three different soil water contents (Helms *et al*., 1997). This indicated that sunflower emergence is sensitive to changes in temperature. Seed and seedling stress increased with an increase in temperature and a decrease in soil water content. This caused a decrease in emergence rate of seedlings when the soil water content was increased to 0.20 kg kg^{-1} six days after subjection to stress treatments. A significant increase of 60 to 95% in emergence was reported with an increase in the soil water content from 0.05 to 0.09 kg kg^{-1}. It was found that sunflower emergence was the lowest at 0.05 kg kg^{-1} soil water content and the highest at a soil water content of 0.09 kg kg^{-1}. Stand establishment of sunflowers and soya bean is therefore most likely to be poor when soil water content is low and temperatures are high (Helms *et al*., 1997).

Adversely, oxygen levels in soil decrease with excessive water and this may also reduce germination and finally emergence levels of seedlings (Basra, 1995). Water excess and vigour of seeds have significant interactions. Water excess at 25°C caused a decrease in sunflower seed germination when seeds have high seed vigour. This may be explained by a lack of oxygen in water excess conditions. Low vigour seed causes greater reductions in germination under these conditions. Thus, water deficiency will have a smaller effect on seed germination than water excess (Albuquerque & De Carvalho, 2003).

2.4.3 Texture

Sunflowers grow best on well-drained soils with a high water-holding capacity, a neutral pH_{water} of 6.5-7.5 and sufficient nutrients. Oxygen, hydrogen, and carbon are obtained from water and air. The rest of the nutrients are obtained from the soil (Fanning, 1994). The structure and texture of soil determines water movement and this affects seed germination and emergence. Originally, sunflowers were produced on sandy loam to clay soils with a clay content of 15-55%. Presently, production takes place in soil with less than 20% clay (Anonymous, 1999). Crusting of the top layer of soil is a major factor that decreases crop emergence (Awadhwal & Thierstein, 1985; Baumhardt *et al.*, 2004).

2.4.3.1 Encrustation

Soil crusts develop when aggregates are dispersed with high energy rainfall and air escapes from aggregates. Aggregates are therefore susceptible to physical and mechanical forces, causing it to break down. Soil particles enter surface pores, thickening and sealing the surface layer. Surface runoff increases sealing of soil surfaces and crusts form after rapid drying out of soil. These crusts form a mechanical barrier to emerging seedlings, depressing infiltration of water and causes serious problems (poor gas exchange and girdling of seedlings) when it forms around the base of seedlings after emergence (Rathore *et al*., 1981; Awadhwal & Thierstein, 1985; Bradford & Huang, 1992; Connolly, 1998; Baumhardt *et al*., 2004). Physical characteristics of soil crusts can be summarised as follows: low porosity, greater mechanical strength, low degree of aggregates and a high bulk density (Awadhwal & Thierstein, 1985). Soil texture is an important variable affecting surface sealing and crusts can form on any soil except sandy soil with low silt and clay content. Soils with high silt and clay content are more susceptible to crust formation but sandy loam soils are more susceptible than clay loam soils. Adequate soil moisture before a rainstorm can decrease crust formation because it determines the aggregate breakdown mechanism (Bradford & Huang, 1992). Low seedling emergence can be explained by low oxygen levels, limited water, and high crust strength (Massingue, 2002). Seedlings that emerge from crusted soil are weaker and smaller than seedlings that emerge from moist soil with no crusts. Young seedlings develop an emergence force to emerge from the soil. If the emergence force is less than the crust resistance to penetration, seedlings bend beneath the crust, causing girdling of seedlings (Massingue, 2002). High crust strength leads to the occasional collapsing of sunflower seedlings at a stress point between the emerging hypocotyl and buried cotyledons. Under severe stress soya bean, usually, may snap at the hook of the hypocotyls. Even if these seedlings manage to emerge successfully, they are weak and are susceptible to insects and diseases and might ultimately die a few days after emergence (Rathore *et al*., 1981; Hyatt *et al*., 2007).

2.4.3.2 Compaction

Compaction of soil also influences crop production and may decrease seedling emergence, root growth, and yield. This is the process where the volume of pores in soil is reduced due to tillage or wheel traffic. Aggregates crumble into smaller pieces, thus changing the distribution of pore size. This causes poor drainage and reduces aeration (Bayhan *et al*., 2002; Botta *et al*., 2006). Soil susceptibility to compaction can increase with an increase in clay and water content (Connolly, 1998). The evaluation of tractor wheel compaction on sunflower emergence shows a decrease in emergence percentages and days until emergence. Wheel traffic after planting on the entire plot area affects the emergence percentage and amount of days it takes for seedlings to emerge from soil. Although it was found that seedlings emerged within 11 days after planting, the percentage of emergence was the lowest of all treatments at 78% (Bayhan *et al.*, 2002). Wheel traffic after planting between rows has the highest count of days for emergence, but still the emergence percentage was 96%. Penetration resistance was high on the soil before emergence and as resistance of the penetrometer reading increased, emergence was delayed and the percentage of seedlings emerging from the soil decreased. Compaction in soil affects the percentage of emergence and days to emergence negatively (Bayhan *et al.*, 2002).

2.5 Conclusion

Sunflowers are well adapted to a wide range of temperatures and soil conditions, but this crop can still experience limitations. The biggest limitation established in South Africa is the emergence of seedlings. Uneven emergence of sunflower seedlings due to high soil temperatures, inadequate soil moisture or planting techniques can lead to an uneven stand and, therefore, lower yields than expected. To understand these losses knowledge is needed on the early growth and development of sunflower, factors affecting this stage and the effect it has on physiological processes. This research will therefore focus on emergence of sunflowers and factors affecting it. Some factors will be manipulated to ensure emergence, highlighting the factors that can still be a limitation to sunflower growth, development, and yield.

CHAPTER 3

EMERGENCE RESPONSE OF SUNFLOWER CULTIVARS (*Helianthus annuus* L.) TO SEED SIZE, PLANTING TECHNIQUES, AND SOIL FACTORS

3.1 Introduction

Sunflower seed size has proven to affect the emergence of sunflower seedlings (Hernández & Orioloi, 1985; Longer *et al*., 1986; Farahani *et al*., 2011). Sunflower seed, a fruit or achene, consists of the seed or kernel inside the pericarp or hull. Seeds (achenes) are graded according to size and the difference between the small and large achenes is clearly visible (Knowles, 1978).

Large seeds are able to generate a larger emergence force than small seeds, resulting in a greater emergence percentage than small seeds (Longer *et al*., 1986; Hocking & Steer, 1989; Kaya & Day, 2008). Large seeds also have a potentially greater food reserve available which is essential during seedling development. Large seeds can therefore develop stronger roots and shoots than smaller seeds (Longer *et al*., 1986; Kaya & Day, 2008).

Small seeds, which have a small hull to kernel ratio, absorb water more efficiently than large seeds. Germination percentage of small seeds is faster than that of large seeds (Saranga *et al*., 1998). Knowing that sunflower seed is graded into different seed sizes, the objective of this chapter was to evaluate the response of sunflower emergence as affected by different seed sizes, planting techniques, and soil factors.

3.2 Materials and Methods

3.2.1 Experimental Design

The experiments were conducted during September 2010, November 2010, and February 2011 in the glasshouses of the Department of Soil, Crop and Climate Sciences at the University of the Free State.

The experiment was laid out as a split-split plot design with four replications. Planting depth was used as the main plot, cultivar as a subplot, and seed size as the sub-sub plot. Three commercially available cultivars (PAN 7049, PAN 7057 and PAN 7063) were planted at two planting depths (25 and 50 mm respectively), on three planting dates (September 2010, November 2010 and February 2011) and in two textured soils (Table 3.1). The different planting dates were used in an attempt to accommodate and assimilate increasing soil temperatures as would be the case over a season.

Table 3.1 Physical and chemical characteristics of the Bainsvlei and Tukulu soil forms as described by Chimungu, (2009) and physical and chemical analysis done with onset of experiments

CHARACTERISTICS	BAINSVLEI FORM	TUKULU FORM
PHYSICAL		
Horizon	A	A
Depth (mm)	0-250	0-270
Texture	Fine loamy sand	Fine sandy loam
Sand (%)	95	86
Silt (%)	0	0
Clay (%)	5.0	14
Bulk density (Mg m^{-3})	1.66	1.67
CHEMICAL		
$pH_{(KCL)}$	4.6	4.3
P (mg kg^{-1}) (Bray 1)	18.0	10.7
K (mg kg^{-1}) (NH_4OA_C)	87.5	250.5
Ca (mg kg^{-1})	207	441
Mg (mg kg^{-1})	88	148

Three seed sizes (seed size one to three, with seed size one being the largest) were used for all the cultivars (seed lots were not specified). Seed size is determined by using round hole gauges and sieves (Anonymous, 2013). The trade values (seed size) for seed size one to three is provided in Table 3.2. All seed sizes are sold commercially and the producers decide which size seed will be planted.

Table 3.2 Round hole gauge sizes for seed size separation (Gauge sizes are provided imperially and were converted to metric units)

Seed size	Inches (in)	mm
One	18/64	7.11
Two	10/64	4.06
Three	8/64	3.18

The experiments were conducted in custom made wooden containers. Four wooden containers (2.4 × 1.2 × 0.3 m) were placed on polystyrene (30 mm thick) for isolation, and the container lined with plastic on the inside to prevent water leakage. The outside of the containers were lined with aluminium foil to prevent heat absorption through radiation. Each container was divided into four blocks, representative of four replications. The containers were filled with Bainsvlei and Tukulu sandy-loam top soil. Some physical and chemical soil characteristics are summarised in Table 3.1. The Bainsvlei soil form was collected at Kennelworth Research Station (29º01’ 00’’ S, 26º08’ 00’’ E, altitude 1354 m) and the Tukulu form was collected at Paradys Research Farm (29º13’ 25’’ S, 26º12’ 08’’ E, altitude 1417 m) of the University of the Free State.

Two planting depths, 25 and 50 mm respectively, were used in combination with the soil forms (Figure 3.1). The containers were filled with soil (sieved with a 2 mm screen) to 245 mm (25 mm planting depth) and 220 mm (50 mm planting depth) respectively. The drained upper limit (DUL) was gravimetrically determined, and soil was wet accordingly. Fifteen seeds of each cultivar were sown in each block. A second layer of soil (15 and 40 mm respectively) was used to cover the seeds. This layer of soil was also wet according to the soil DUL. Dry soil (10 mm) was placed on top to prevent encrustation. Two weeks after planting the soil was wet with 20 litres of water for each container to prevent any form of drought stress.

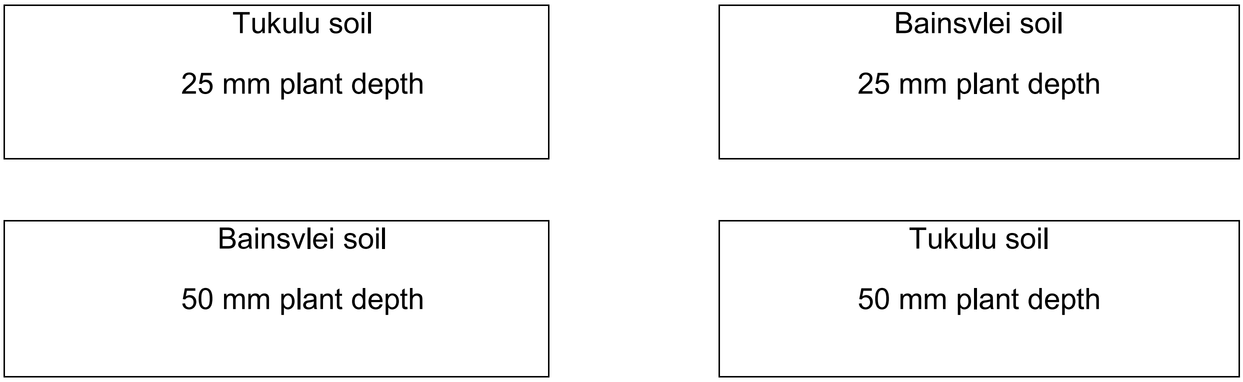


Figure 3.1 Experimental layout of the containers with two soil types and planting depths.

The measured DUL before planting for the Bainsvlei soil was 0.18 kg kg^{-1}, and, for the Tukulu soil, 0.21 kg kg^{-1}. Soil temperature and soil moisture were monitored hourly at each planting depth with data loggers. Day/night soil temperatures were monitored with Hobo channel loggers at hourly intervals. Average of day and night temperatures was determined for 7 days after planting during the critical stage of emergence for the two different soil forms (Figure 3.2).

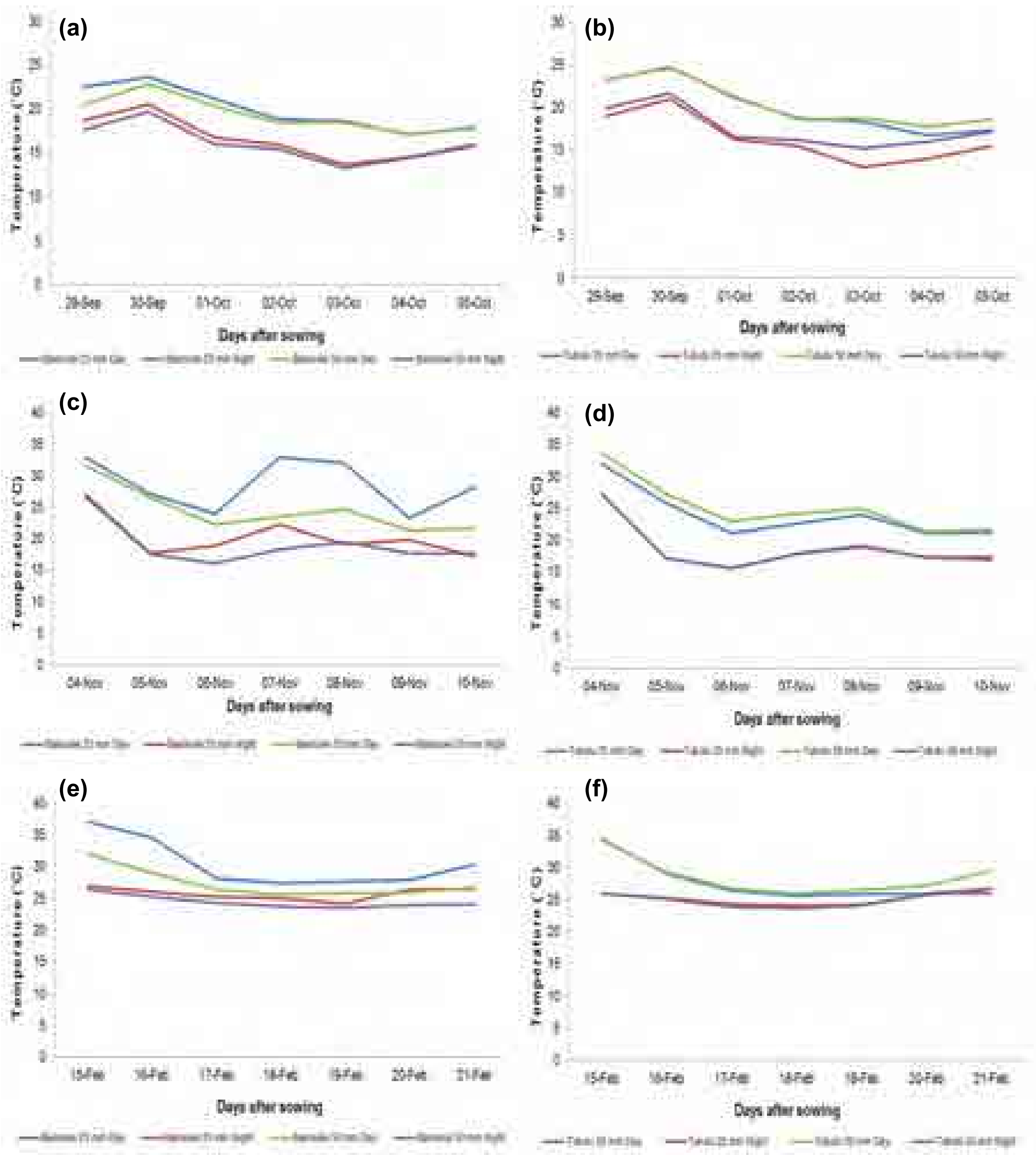


Figure 3.2 Day and night temperatures during September 2010 of the (a) Bainsvlei and (b) Tukulu soil, November 2010 of the (c) Bainsvlei and (d) Tukulu soil and during February 2011 of the (e) Bainsvlei and (f) Tukulu soil.

3.2.2 Parameters

Seedling emergence

The number of emerged seedlings was recorded for 14 consecutive days. The appearance of the open cotyledons above soil surface was an indication of emergence. Emergence percentages (E%) were determined by dividing the number of emerged seeds by the total number of seeds sown, multiplied by 100. Emergence index (EI), as modified and defined by Nel (1998a), was calculated as $EI = A_0 + A_1(0.95) + ... + A_6(0.45)$, where A is the percentage of hypocotyls that emerged from the soil. A_0 represented the day when emergence of cultivars (day 3 was used as a standard) commenced and A_6 represented day nine after planting.

Plant height

Plant height was recorded for 10 randomly selected plants from each plot with termination of the experiment (21 days after plant). Height was measured in mm from soil level to growing tips and finally the average plant height per plant was determined.

Fresh mass and dry mass

Fresh mass (g) of the 10 selected plants per cultivar was determined and oven dried at 50°C for 78 hours with termination of the experiment. The dry mass (g) of the plants was weighed and an average per plant determined.

Leaf area

Leaf area (cm^2) of 10 randomly selected plants was measured with a LI-COR 3100 leaf area meter and expressed on a per plant basis. It was measured with termination of the experiment (21 days after plant).

Statistical analysis

Data was analysed using the statistical program SAS 9.2® and significant differences between means were analysed using Tukey's Least Significant Test at the 5% probability level.

3.3 Results

Analysis of variance of sunflower plants as affected by planting depth, planting date, different seed size, and cultivar at two soil textures is summarised in Table 3.3. Seed size significantly affected emergence index (EI) and cultivar significantly affected leaf area respectively for all three planting dates in the Bainsvlei soil. Emergence index was significantly affected by cultivars in the Tukulu soil for all the planting dates. Leaf area and dry mass was affected by seed size during November 2010 and February 2011 in the Bainsvlei soil and during September 2010, November 2010 and February 2011 in the Tukulu soil. All parameters were significantly affected by planting depth during September 2010 for both the Bainsvlei and Tukulu soil.

Table 3.3 Summarised analyses of variance of growth parameters response to treatment factors in Bainsvlei and Tukulu soil (Planting depth = PD, Cultivars = C, Seed sizes = SS)

Crop growth parameters	Factors	Bainsvlei Soil Sept 2010	Bainsvlei Soil Nov 2010	Bainsvlei Soil Feb 2011	Tukulu soil Sept 2010	Tukulu soil Nov 2010	Tukulu soil Feb 2011
Emergence Index	PD	*	ns	*	*	ns	*
	Cultivar	*	ns	*	*	*	*
	PD x C	*	ns	ns	ns	ns	ns
	Seed size	*	*	*	ns	ns	ns
	PD x SS	ns	ns	ns	ns	ns	ns
	C x SS	ns	ns	ns	ns	ns	ns
	PD x C x SS	ns	ns	ns	ns	ns	ns
Plant height	PD	*	ns	ns	*	*	*
	Cultivar	*	ns	ns	ns	ns	ns
	PD x C	ns	ns	ns	ns	ns	ns
	Seed size	ns	*	ns	*	ns	ns
	PD x SS	ns	ns	ns	ns	ns	ns
	C x SS	ns	ns	*	ns	ns	ns
	PD x C x SS	ns	ns	ns	ns	ns	ns
Leaf area	PD	*	ns	ns	*	*	ns
	Cultivar	*	*	*	*	*	ns
	PD x C	ns	ns	ns	ns	ns	ns
	Seed size	ns	*	*	*	*	*
	PD x SS	ns	ns	ns	ns	*	ns
	C x SS	ns	ns	ns	ns	*	ns
	PD x C x SS	ns	ns	ns	*	*	ns
Dry mass	PD	*	*	ns	*	ns	ns
	Cultivar	ns	*	ns	*	ns	*
	PD x C	ns	ns	ns	ns	ns	*
	Seed size	ns	*	*	*	*	*
	PD x SS	ns	ns	ns	ns	ns	*
	C x SS	ns	ns	ns	ns	*	*
	PD x C x SS	ns	ns	ns	ns	*	*

* = significantly different, ns = not significant

3.3.1 Emergence Index

Bainsvlei:

Emergence index (EI) showed significant differences for planting depth during September 2010 and February 2011. Emergence index was also significantly higher at 25 mm planting depth than at 50 mm for both planting dates (Figure 3.3).

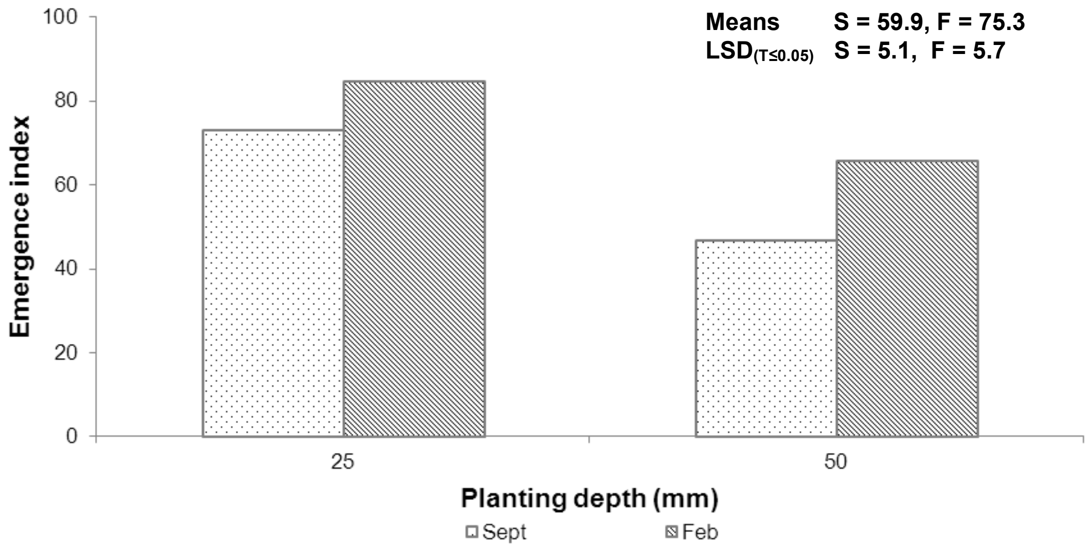


Figure 3.3 Emergence index (EI) at two planting depths during September 2010 (S) and February (F) 2011 in the Bainsvlei soil.

Emergence index was significantly influenced by cultivars during February 2011 according to the analysis of variance (ANOVA). Separating these means at P ≤0.05 showed no significant differences using the Tukey test. This occurrence is the result of the strictness of the Tukey test (results not shown).

Emergence index (EI) was significantly affected by the cultivar by planting depth interaction during September 2010 (Table 3.4). Emergence index of PAN 7057 at 25 mm planting depth was significantly higher than the EI of PAN 7049, PAN 7057, and PAN 7063 at 50 mm planting depth. PAN 7049 and PAN 7063 EI at 25 mm planting depth was also significantly higher than the EI at 50 mm planting depth for the same cultivars (Table 3.4). The EI of PAN 7057 showed a decline of 21% from a planting depth of 25 to 50mm compared to a decline of 27% and 31% for PAN 7063 and PAN 7049, respectively.

Table 3.4 Emergence index of three cultivars with different seed sizes during September 2010 in the Bainsvlei soil

Cultivar	**Planting depth (mm)**		
	25	**50**	**Average**
PAN 7049	73.94	42.72	**58.33**
PAN 7057	79.00	57.94	**68.47**
PAN 7063	66.53	39.53	**53.03**
Average	**73.16**	**46.73**	
$LSD_{(T\leq0.05)}$ PD x C = 20.3			

Emergence index (EI) was significantly affected by seed size for all the planting dates (Figure 3.4). Emergence index of seed size one was significantly lower than that of seed size two and three during September 2010 while the EI of seed size one was significantly lower than that of seed size three during November 2010 and February 2011. During September 2010 the EI of all three seed sizes was significantly lower than that of November 2010 and February 2011. Recorded EI of February 2011 was the highest for seed size two and three (Figure 3.4).

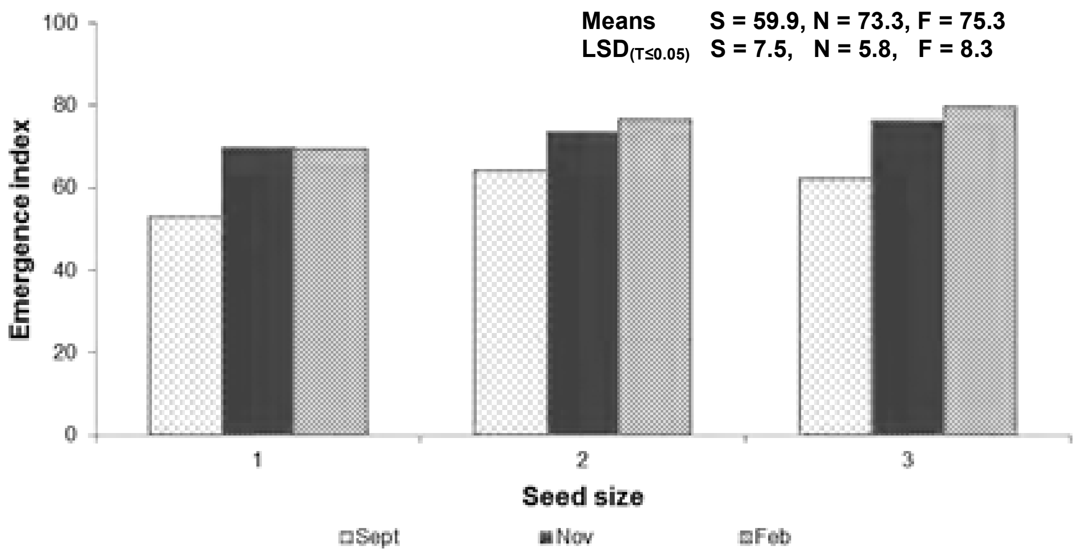


Figure 3.4 Emergence index (EI) of seed size during September (S), November (N) 2010 and February (F) 2011 in the Bainsvlei soil.

Tukulu:

Planting depth significantly affected EI of September 2010 and February 2011 (Figure 3.5) in the Tukulu soil. Emergence index was significantly higher during February 2011 than during September 2010 for both planting depths. Emergence index was also significantly higher at 25 mm planting depth than at 50 mm for both planting dates. The highest recorded EI was recorded during February 2011 at 25 mm planting depth.

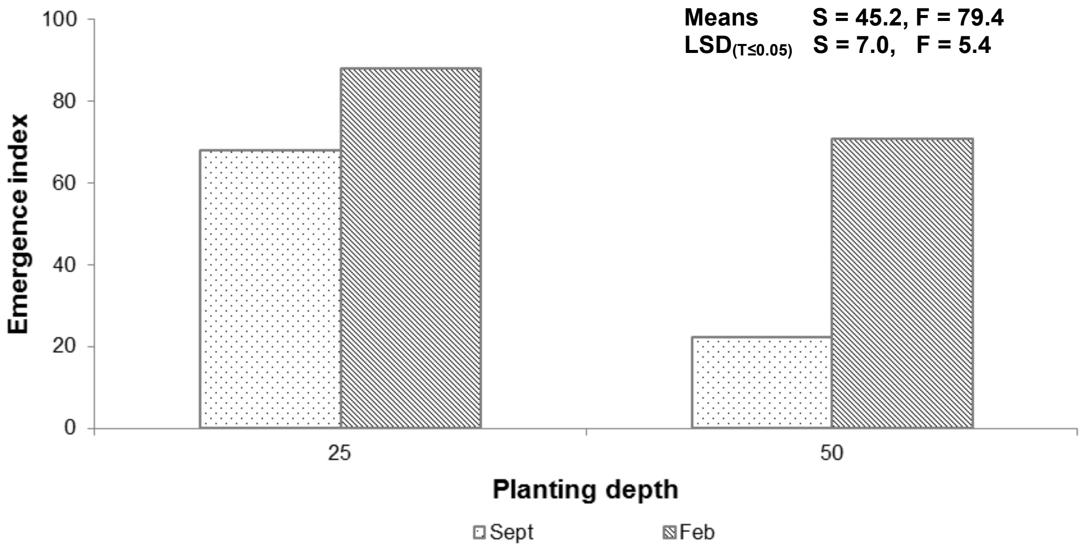


Figure 3.5 Emergence index (EI) at two planting depths during September (S) 2010 and February (F) 2011.

Emergence index (EI) was significantly affected by cultivar during September 2010, November 2010, and February 2011. Emergence index of PAN 7057 was significantly higher than that of PAN 7063 during September 2010 as well as PAN 7049 and PAN 7063 during February 2011. Generally EI was higher during February 2011 than during September 2010 (Figure 3.6). During November 2010 cultivars significantly affected EI according to the ANOVA. Separating these means at P ≤0.05 showed no significant differences using the Tukey test. This occurrence is the result of the strictness of the Tukey test (results not shown).

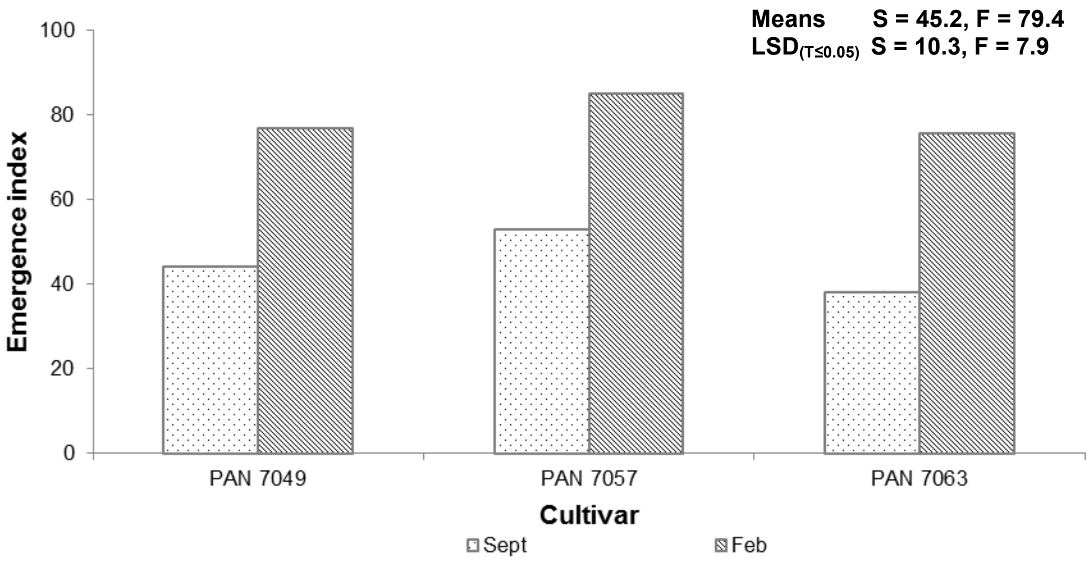


Figure 3.6 Emergence index (EI) response to different cultivars during September (S) 2010 and February (F) 2011 in the Tukulu soil.

3.3.2 Plant Height

Plant height (mm) was recorded with termination of the experiment (21 days after planting).

Bainsvlei:

Plants were significantly taller when planted at 20 mm than plants planted at 50 mm (Figure 3.7).

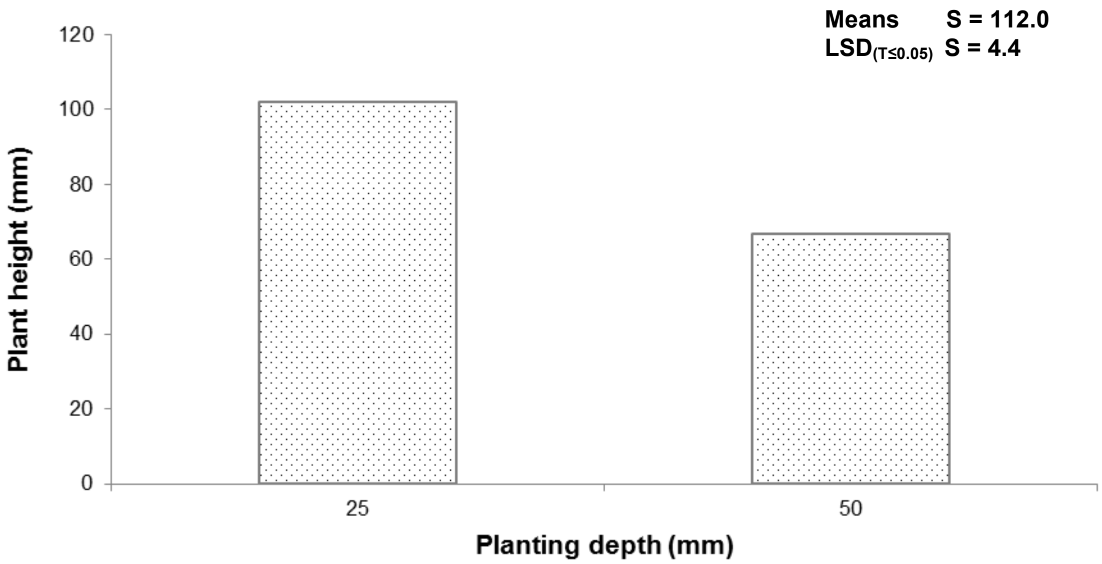


Figure 3.7 Plant height of seedlings planted during September at two planting depths in the Bainsvlei soil.

Plant height was significantly affected by cultivars during September 2010. Plant height of PAN 7057 was significantly greater than that of PAN 7049 and PAN 7063 while plants of PAN 7049 were the smallest (Figure 3.8).

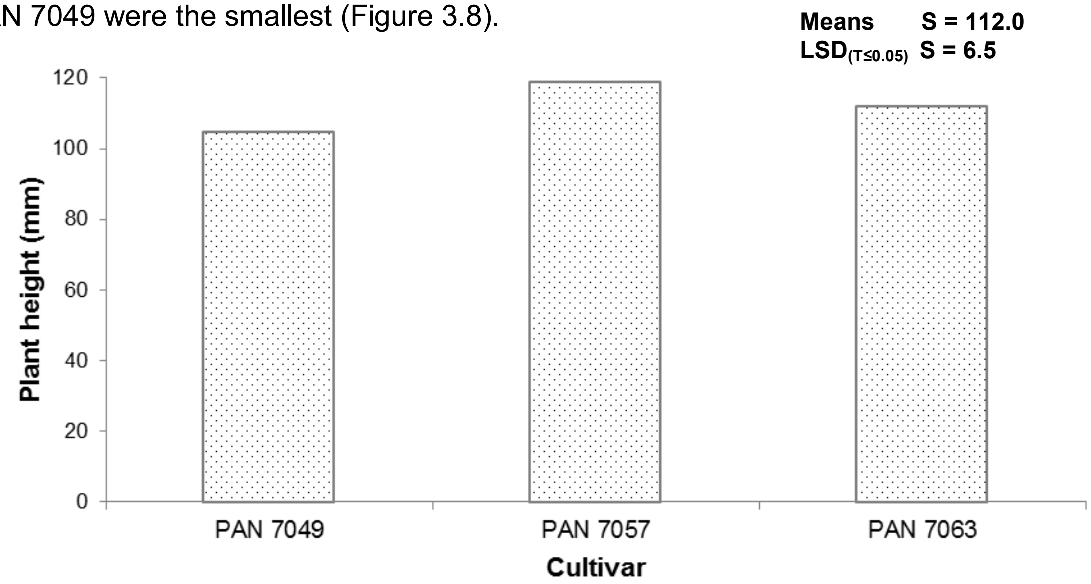


Figure 3.8 Plant heights of cultivars during September 2010 in the Bainsvlei soil.

Seed size significantly affected plant height during November 2010 (Figure 3.9). Seed size two resulted in significantly taller plants during November 2010 than plants of seed size one. Plant height of the plant of seed size three was neither significantly taller nor shorter than that of seed size two or one, respectively.

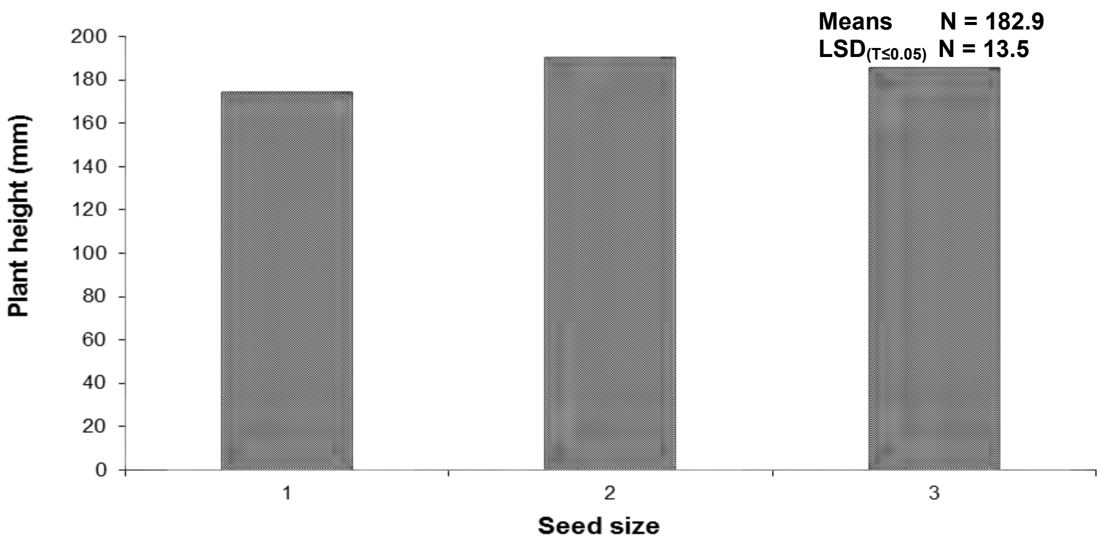


Figure 3.9 Plant height as affected by different seed sizes during November (N) 2010 in the Bainsvlei soil.

Tukulu:

Plants were significantly taller at 25 mm planting depth during all the planting dates than at 50 mm. The November 2010 planting produced the tallest plants at 25 mm planting depth compared to any other planting date or depth (Figure 3.10).

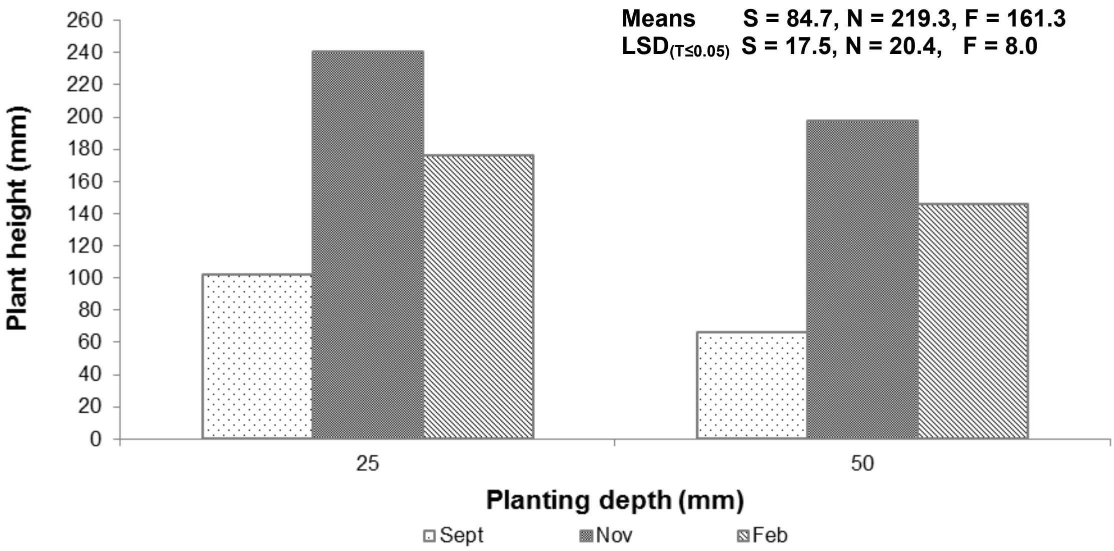


Figure 3.10 Plant height as affected by planting date (September (S), November (N) 2010 and February (F) 2011) and planting depth in the Tukulu soil.

Plant height of plants of seed size one was significantly taller than that of seed size three during September 2010. Plant height of plants of seed size two indicated no significant difference from the plant height of plants of seed size one and three (Figure 3.11).

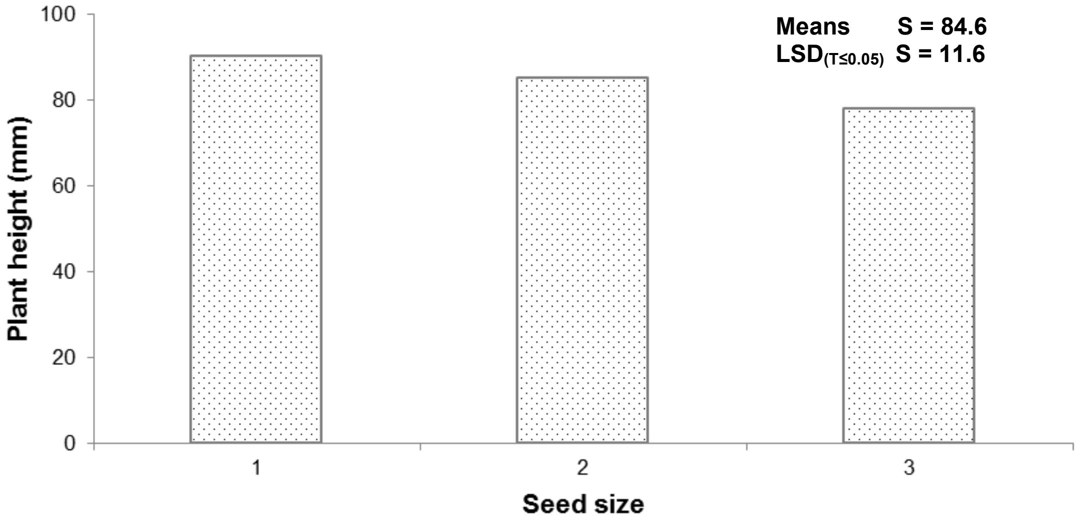


Figure 3.11 Plant height as affected by seed sizes and planting date during September 2010 in the Tukulu soil.

3.3.3 Leaf Area

Bainsvlei:

Leaf area of plants planted in September 2010 was significantly greater at a planting depth of 25 mm compared to the leaf area of plants planted at 50 mm (Figure 3.12).

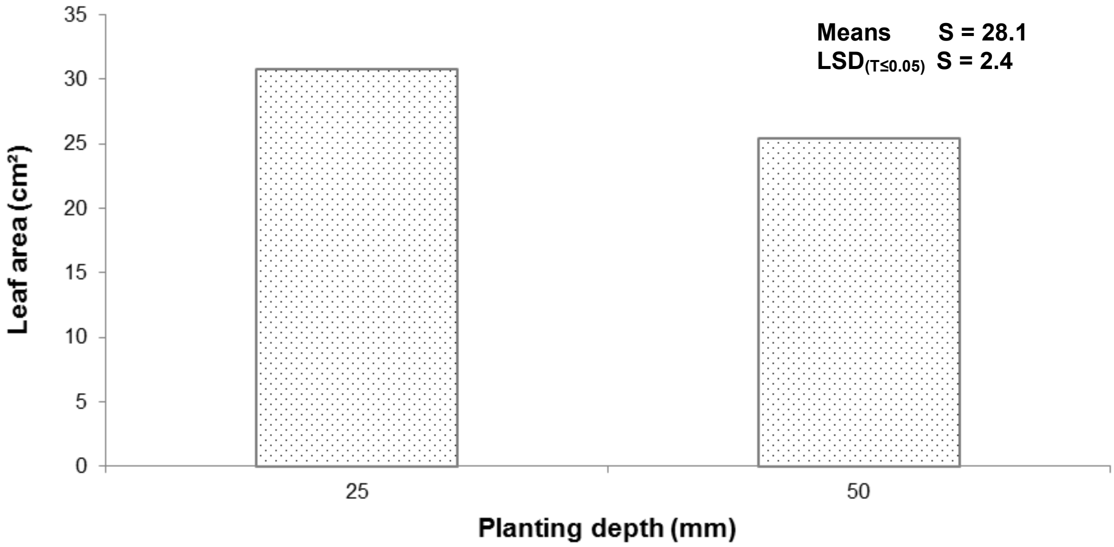


Figure 3.12 Leaf area as affected by two planting depths during September 2010 in Bainsvlei soil.

Leaf area was also significantly affected by cultivar for all the planting dates. Leaf area of PAN 7057 and PAN 7063 was significantly greater than that of PAN 7049 during September 2010 and February 2011. During November 2010 the leaf area of PAN 7063 was significantly greater than that of PAN 7049 and PAN 7057. The smallest leaf area was recorded during November 2010 (Figure 3.13).

Seed size had a significant effect on leaf area during November 2010 and February 2011 (Figure 3.14). Leaf area was generally greater during February 2011 than November 2010. The greatest leaf area was recorded for seed size two while seed size three had the smallest recorded leaf area for both planting dates (Figure 3.14).

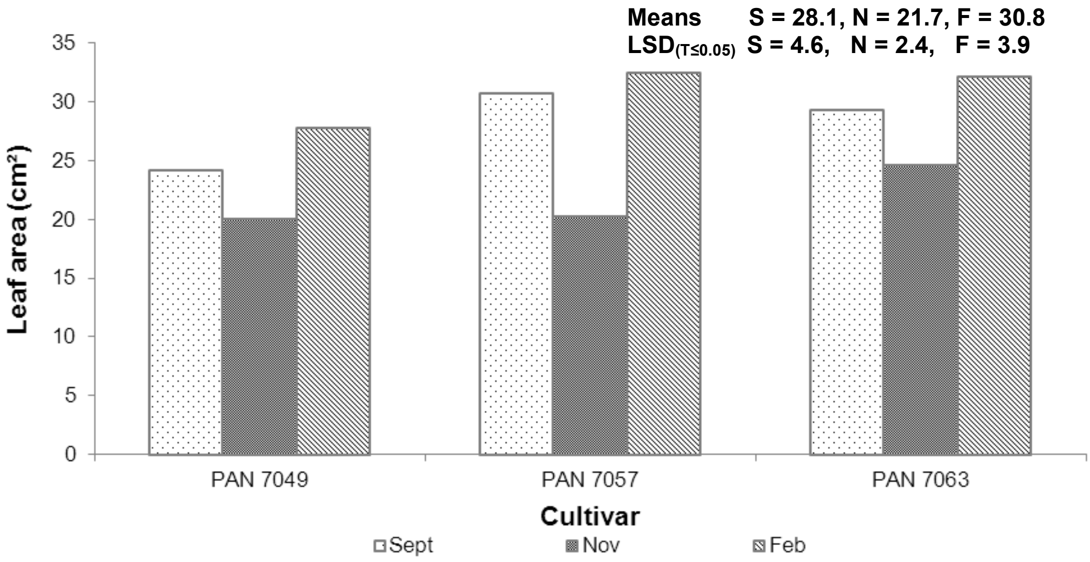


Figure 3.13 Leaf area as affected by cultivars during September (S), November (N) 2010 and February (F) 2011 in Bainvlei soil.

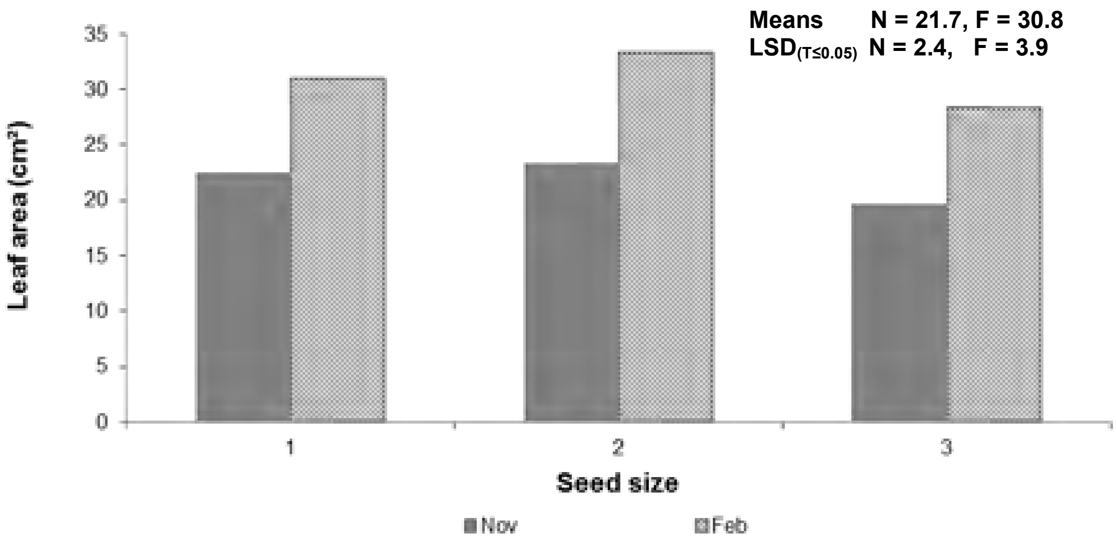


Figure 3.14 Leaf area as affected by planting date (November (N) 2010 and February (F) 2011 and seed size in Bainsvlei soil.

Tukulu:

Seed size significantly influenced leaf area during February 2011. Leaf area of plants from seed size one was significantly greater than that of seed size three (Figure 3.15).

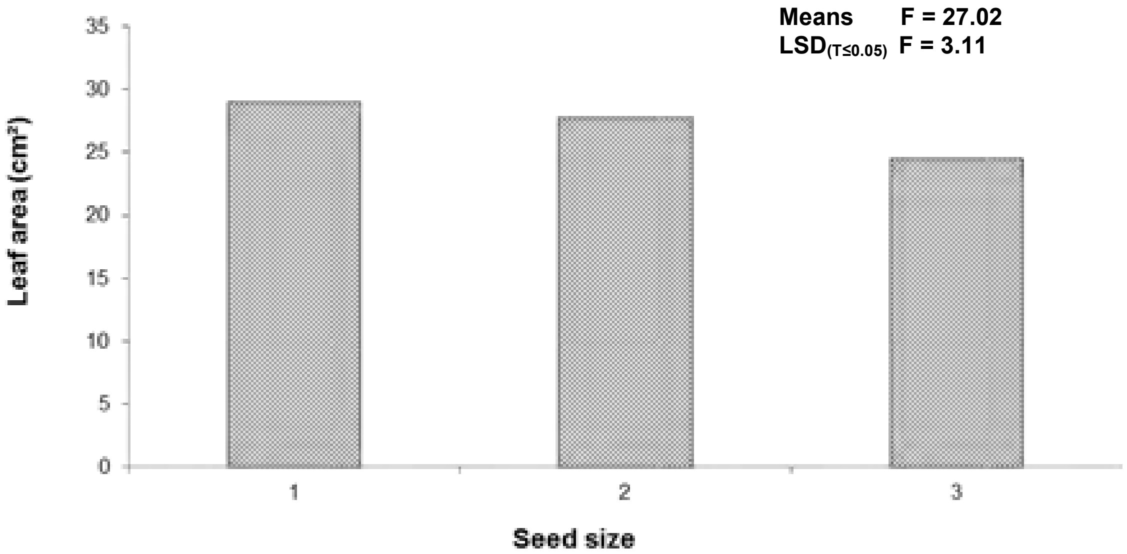


Figure 3.15 Leaf area as affected by seed size during February 2011 in Tukulu soil.

Leaf area of plants planted in September 2010 showed significant differences through the interaction of cultivar, planting depth and seed size (Table 3.5). Leaf area determined from PAN 7049 seed size one, two and three at 25 mm planting depth was significantly greater than that of the same seed sizes planted at 50 mm. Recorded leaf area of PAN 7057, seed size one and two at 25 mm planting depth was significantly greater than that at 50 mm planting depth. The leaf area of all three seed sizes of PAN 7063 was significantly greater at 25 mm than at 50 mm planting depth. The greatest leaf area was recorded for PAN 7057 seed size one at 25 mm planting depth and the smallest leaf area was recorded for PAN 7049 seed size one at 50 mm planting depth. Generally leaf area of plants was greater for seed size one and two compared to that of seed size three, especially at a planting depth of 25 mm. Leaf area of plants planted at 25 mm was significantly greater than that planted at 50 mm (Table 3.5). Although an interaction effect (PD x SS) was found it has to be noted that the overall leaf area of PAN 7057 and PAN 7063 at both planting depths were greater than that of PAN 7049. The reduction in leaf area of plants planted at planting depth 25 to 50 mm was ≈ 24.4% for PAN 7057 and PAN 7063 compared to a leaf area reduction of 35.5% for PAN 7049. Nearly no reduction in leaf area was observed for seed size one and two. The leaf area of plants from seed size three was only ≈ 13% smaller than that of seed size one and two. This proves that cultivar (genetic) differences are greater than the effect of seed size (Table 3.5).

Table 3.5 Leaf area of three sunflower cultivars with different seed sizes at two planting depths during September 2010 in Tukulu soil

Planting depth (mm)							
	25			50			
Seed size	**PAN 7049**	**PAN 7057**	**PAN 7063**	**PAN 7049**	**PAN 7057**	**PAN 7063**	**Average**
1	20.25	26.98	25.18	11.03	19.56	19.23	**20.24**
2	19.35	25.05	25.01	14.67	18.79	17.79	**20.11**
3	18.48	18.34	22.91	11.73	18.79	14.32	**17.56**
Average	**19.36**	**23.46**	**24.37**	**12.48**	**19.05**	**17.12**	
$LSD_{(T \leq 0.05)}$ PD x C x SS = 4.65							

November 2010 planting also resulted in a three way interaction that significantly affected leaf area (Table 3.6). Leaf area of plants from all seed sizes of PAN 7049 at 25 mm planting depth was significantly greater than that at 50 mm. Plants of seed size one and two of PAN 7057 showed a significant greater leaf area at 25 mm planting depth than at 50 mm. Leaf area of plants from seed size two and three of PAN 7063 was significantly greater at 25 mm than at 50 mm planting depth. The average leaf area of plants of seed size one was overall greater than that of seed size three. The greatest leaf area was recorded for PAN 7057 seed size one at 25 mm while the smallest leaf area was recorded for PAN 7049 seed size one at 50 mm. Similarly to the discussion of Table 3.5 leaf area of PAN 7049 for all seed sizes at 25 and 50 mm planting depth was consistently smaller than that of PAN 7057 and PAN 7063 (Table 3.6).

Table 3.6 Leaf area of three sunflower cultivars with different seed sizes at two planting depths during November 2010 in Tukulu soil

Planting depth (mm)							
	25			50			
Seed size	**PAN 7049**	**PAN 7057**	**PAN 7063**	**PAN 7049**	**PAN 7057**	**PAN 7063**	**Average**
1	25.84	35.05	29.76	18.84	25.17	25.57	**28.37**
2	29.95	31.30	35.01	21.99	22.92	22.81	**27.33**
3	26.19	26.81	30.07	19.33	22.25	25.99	**25.11**
Average	**27.33**	**31.05**	**31.61**	**20.05**	**23.45**	**28.12**	
$LSD_{(T \leq 0.05)}$ PD x C x SS = 5.07							

3.3.4 Dry Mass

Bainsvlei:

Dry mass showed significant differences between two planting depths during September and November 2010 (Figure 3.16). The greatest dry mass was recorded at 25 mm planting depth for both planting dates and a significant smaller dry mass was recorded during September 2010 at 50 mm (Figure 3.16).

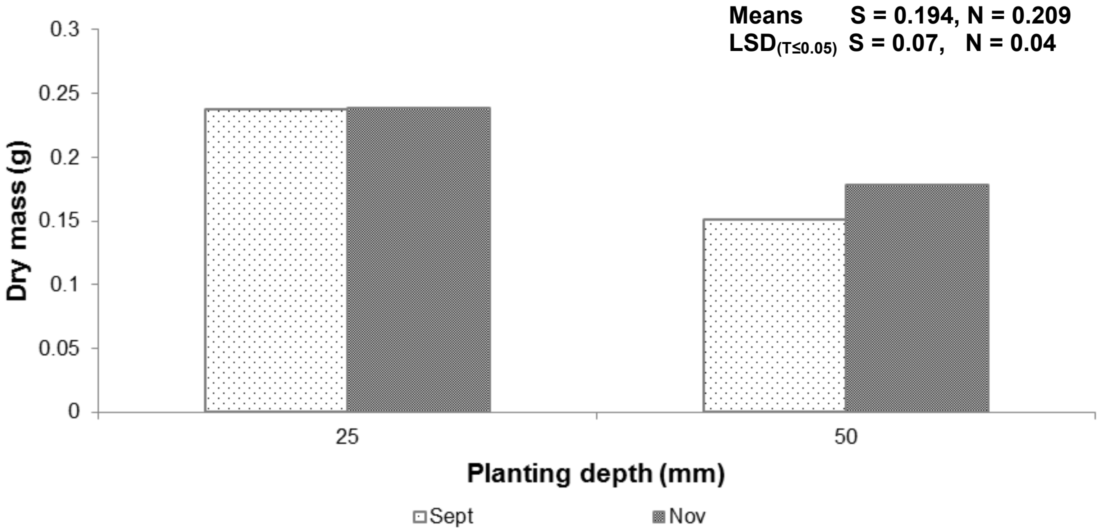


Figure 3.16 Dry mass planted at two planting depths during September (S) and November (N) 2010 in Bainsvlei soil.

Dry mass of plants was significantly affected by cultivar during November 2010. Dry mass of PAN 7063 was significantly greater than PAN 7049 and PAN 7057 while the dry mass of PAN 7049 was significantly smaller than both PAN 7057 and PAN 7063 (Figure 3.17).

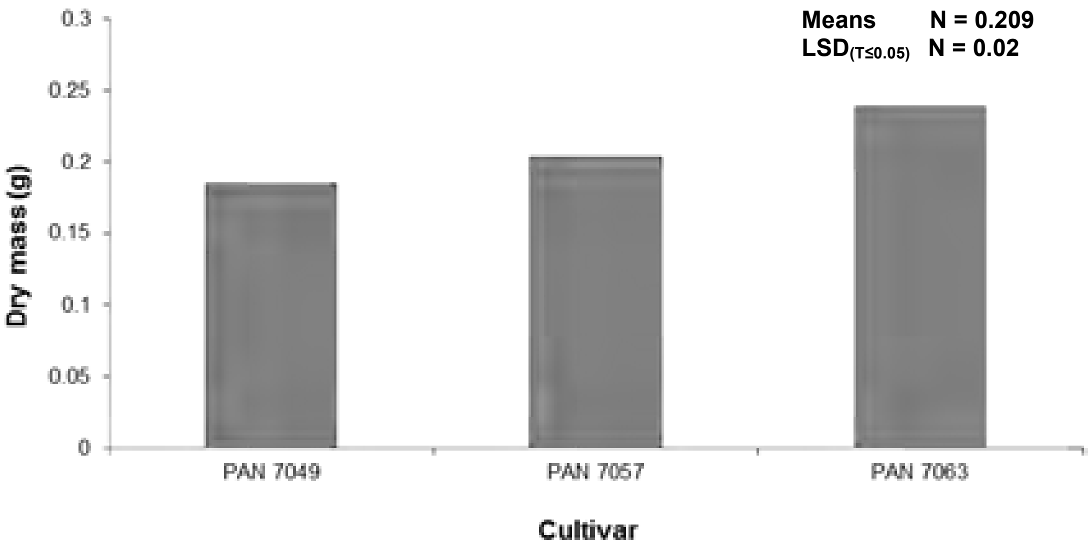


Figure 3.17 Dry mass as affected by different cultivars during November 2010 in Bainsvlei soil.

Significant differences in above ground plant dry mass was recorded for different seed sizes during November 2010 and February 2011 (Figure 3.18). Dry mass was significantly greater during February 2011 than November 2010. The greatest dry mass was recorded for plants of seed size two at both planting dates. Dry mass for plants of seed size three was the smallest during both planting dates (Figure 3.18).

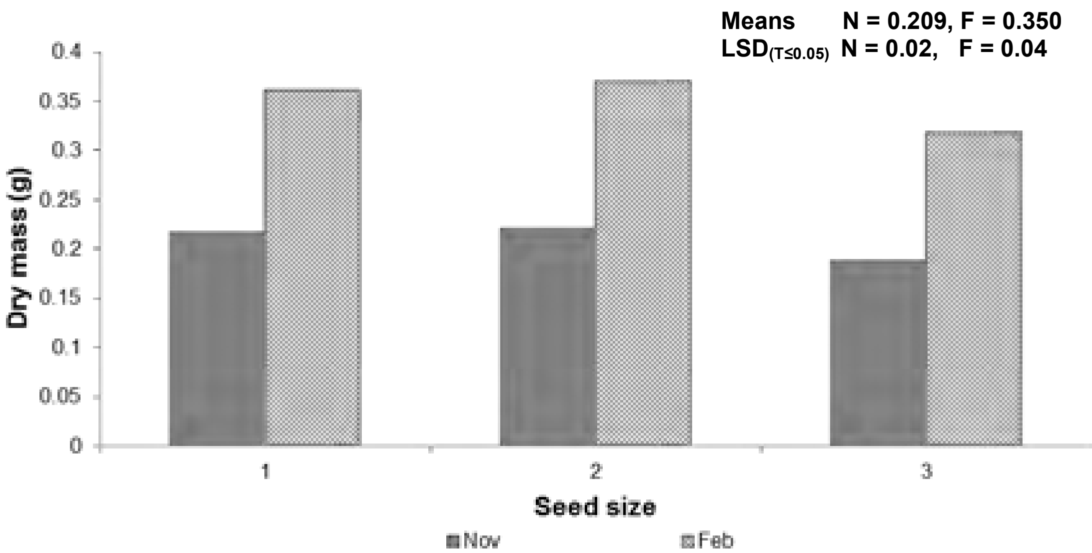


Figure 3.18 Dry mass of different seed sizes during November (N) 2010 and February (F) 2011 in Bainsvlei soil.

Tukulu:

Planting depth during September 2010 significantly affected plant dry mass with the greatest dry mass recorded at 25 mm planting depth (Figure 3.19). Dry mass was significantly affected by cultivar during September 2010. Dry mass of PAN 7057 and PAN 7063 was significantly greater than PAN 7049 (Figure 3.20). Dry mass was also significantly affected by seed size during September 2010. The greatest dry mass was recorded for plants of seed size one and the smallest recorded dry mass by plants of seed size three (Figure 3.21).

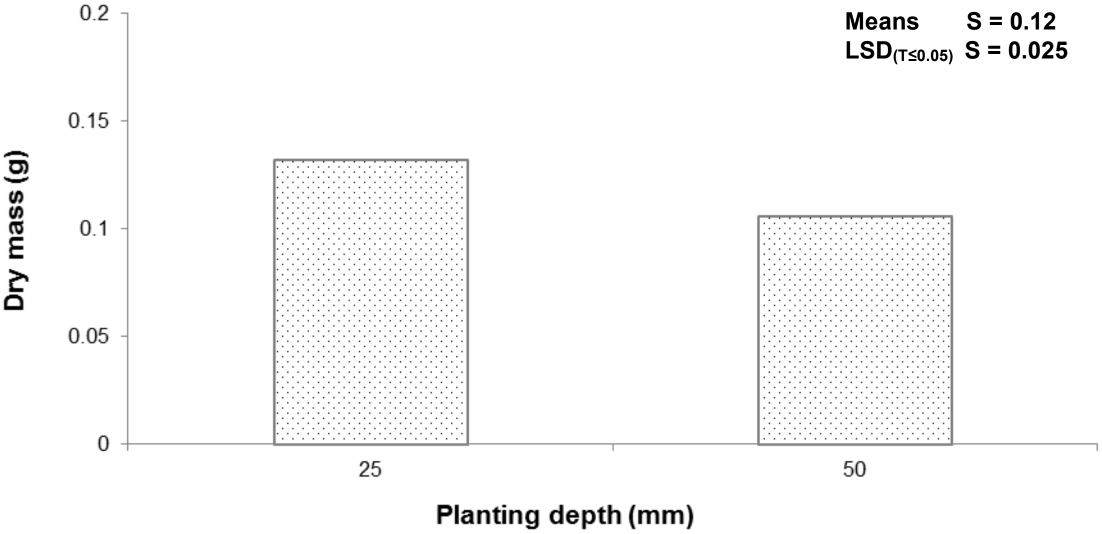


Figure 3.19 Dry mass as affected by planting depth during September 2010 in the Tukulu soil.

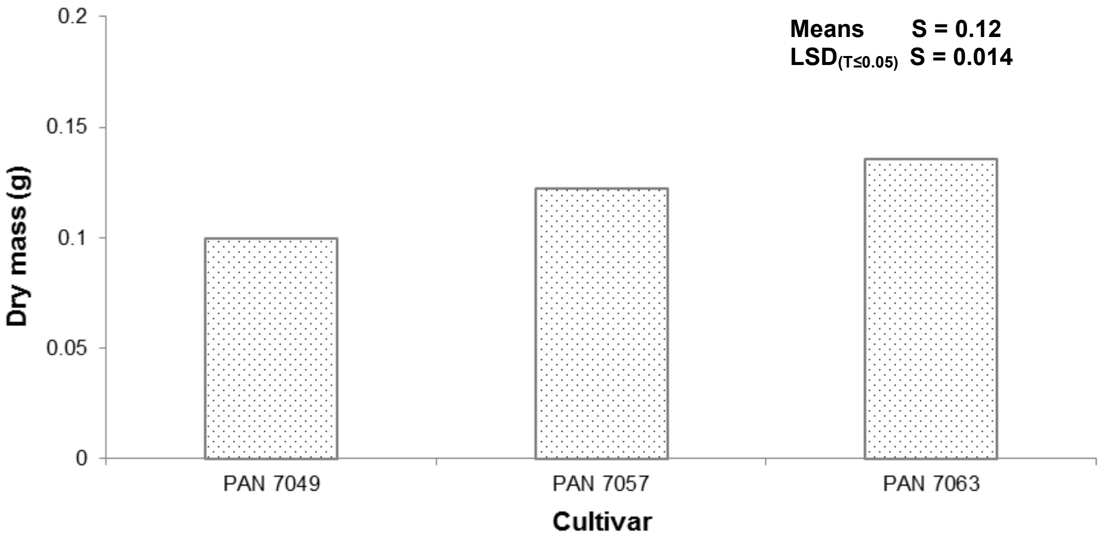


Figure 3.20 Dry mass as affected by different cultivars during September 2010 in the Tukulu soil.

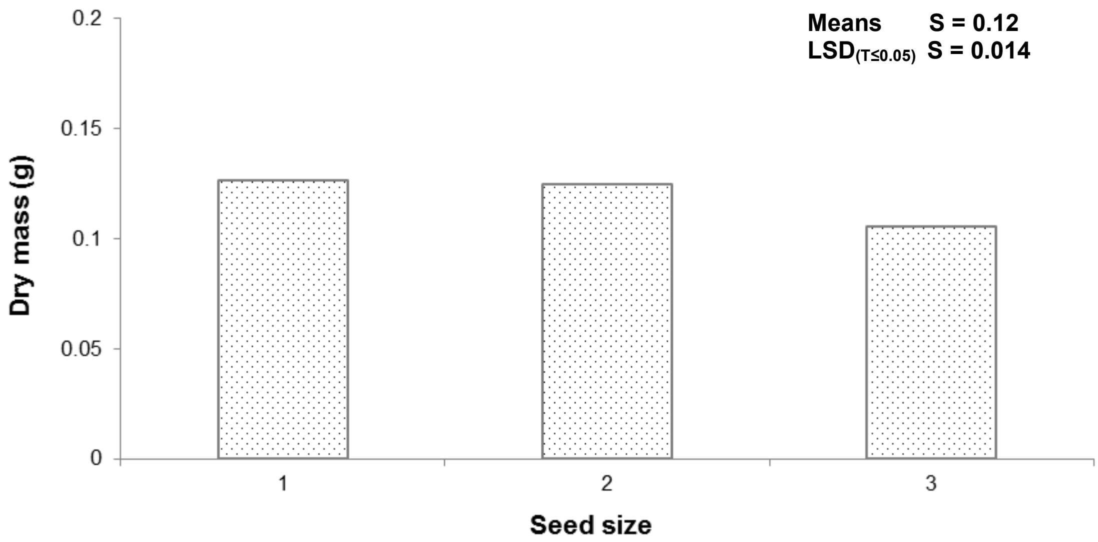


Figure 3.21 Dry mass as affected by seed size during September 2010 in Tukulu soil.

Above ground plant dry mass was significantly affected by the three-way interaction of cultivar, planting depth and seed size during November 2010 (Table 3.7). The dry mass determined from PAN 7057 and PAN 7063 seed size one and two was significantly greater than that of PAN 7049 at 25 mm planting depth. The dry mass of plants of seed size one of PAN 7057 and PAN 7063 showed a significant greater dry mass than that of seed size one of PAN 7049 at 50 mm planting depth. The dry mass of plants determined from seed size one and two of PAN 7057 was significantly greater than that of seed size three at 25 mm planting depth. The greatest dry mass was recorded for PAN 7057 seed size one at 25 mm planting depth. The smallest dry mass was recorded for PAN 7049 seed size one at 50 mm planting depth. No significant differences were recorded for dry mass for all seed sizes of PAN 7049 and PAN 7063 at both planting depths (Table 3.7).
The dry mass of plants of PAN 7049 for all seed sizes at both 25 and 50 mm planting depth was generally smaller (≈ 19%) than the dry mass of PAN 7057 and 7063 (Table 3.7)

Table 3.7 Dry mass of three different cultivars with different seed sizes at two planting depths during November 2010 in the Tukulu soil

	Planting depth (mm)						
	25			50			
Seed size	**PAN 7049**	**PAN 7057**	**PAN 7063**	**PAN 7049**	**PAN 7057**	**PAN 7063**	**Average**
1	0.194	0.302	0.255	0.171	0.247	0.244	**0.235**
2	0.224	0.267	0.297	0.209	0.226	0.226	**0.242**
3	0.216	0.208	0.248	0.187	0.211	0.247	**0.220**
Average	**0.211**	**0.259**	**0.267**	**0.189**	**0.228**	**0.239**	
$LSD_{(T\leq0.05)}$ PD x C x SS = 0.045							

Above ground dry mass of plants was significantly affected by the three-way interaction of cultivar, planting depth and seed size during February 2011 (Table 3.8). The average dry mass of plants of PAN 7063 (seed size two, planting depth 25 mm) and PAN 7057 (seed size two, planting depth 50 mm) was 41% greater than that of PAN 7049 and PAN 7057 seed size three at 25 mm and 50 mm planting depth. When the dry mass of PAN 7057 (0.028 g) was excluded the dry mass difference was reduced to 24% only (Table 3.8).

Table 3.8 Dry mass of three sunflower cultivars with different seed sizes at two planting depths during February 2011 in the Tukulu soil

	Planting depth (mm)						
		25			50		
Seed size	**PAN 7049**	**PAN 7057**	**PAN 7063**	**PAN 7049**	**PAN 7057**	**PAN 7063**	**Average**
1	0.324	0.326	0.344	0.286	0.333	0.327	**0.323**
2	0.326	0.312	0.360	0.296	0.353	0.343	**0.332**
3	0.275	0.028	0.315	0.276	0.262	0.319	**0.240**
Average	**0.308**	**0.222**	**0.339**	**0.286**	**0.316**	**0.329**	
$LSD_{(T\leq0.05)}$ PD x C x SS = 0.066							

3.4 Discussion

Longer *et al*. (1968) stated that seedlings from larger seeds developed a greater emergence force and stronger shoots than smaller seeds, but the opposite was evident in this experiment. Seed size one, the larger seed size, showed a smaller emergence index and plant height than seed sizes two and three (smaller seeds). These results concur with the findings of Farahani *et al*. (2011) that larger seeds show a smaller germination and emergence rate. Emergence of sunflower was faster during February 2011 than during September and November 2010. This could be explained by the differences in soil temperatures that were recorded. Average recorded soil temperature during the day was ±29°C at 25 mm planting depth and ±28°C at 50 mm planting depth during February 2011 for both soils. Emergence was slower at cooler soil temperatures that were recorded during September (±20°C) and November 2010 (24-26°C) at both soils during the day. This corresponds with the findings of Gay *et al*. (1991) that a correlation exists between soil temperature and germination rate.

Hocking and Steer (1989) found that plants grown from small seeds were shorter compared to large seeds and contradicted the findings of this experiment when grown in a Bainsvlei soil. Plants grown from smaller seeds (seed size two) were taller than plants grown from larger seeds (seed size one) in the Bainsvlei soil. This was also only true during November 2010. Plants grown in the Tukulu soil during September 2010 confirmed the statement of Hocking and Steer (1989). Leaf area and dry mass of planats of seed size two was greater in the Bainsvlei soil, but in the Tukulu soil plants of seed size one obtained a greater leaf area and dry mass than that of seed size two and three. The leaf area of PAN 7049 and PAN 7057 seed size one at 25 mm planting depth was greater than that at 50 mm during September 2010 in the Tukulu soil. Dry mass of PAN 7057 and PAN 7063 seed size one and two was greater than PAN 7049. The dry mass determined from seedlings was greater at 25 mm planting depth than at 50 mm in the Tukulu soil during November 2010. Although plants obtained taller and greater leaf area during November 2010 the opposite was evident for emergence and dry mass in the Bainsvlei soil. Emergence of sunflower seedlings was faster during February 2011 in the Bainsvlei soil. According to Sharatt & Gesch (2004) above ground plant biomass can decrease with a delay in planting date. The opposite was evident during the experiment when dry mass of plants was the greatest during February 2011 (late planting).

Seedlings grown from different seed sizes obtained a faster emergence, greater plant height, leaf area and dry mass at a planting depth of 25 mm than at 50 mm during all three planting dates. It is therefore evident that a planting depth of 25 mm was superior than at 50 mm.

3.5 Conclusion

Although seed size play a small role in emergence and growth of sunflower seedlings it was evident that there were differences between results obtained from seedlings with different seed sizes. Large and small seeds (fruits/achenes) can have both positive and negative reactions on emergence and growth of sunflower seedlings. Small seeds are able to emerge faster due to smaller cavities between the hull and kernel. Large seeds, indicated, may develop greater and greater dry masses. For this reason it was decided to standardise the seed size for further experiments. Seed size three was used for experiments described in Chapter 4 and 5.

CHAPTER 4

INFLUENCE OF PLANTING TECHNIQUES AND SOIL FACTORS ON THE EMERGENCE RESPONSE OF SUNFLOWER CULTIVARS (*Helianthus annuus* L.)

4.1 Introduction

Seedling emergence is one of the vital stages during sunflower establishment. Sunflower establishment commences with seed germination, appearance of the radicle (formation of seedling root), hypocotyl emergence, and seedling emergence through the soil surface. During the final step of emergence the hypocotyl pulls the cotyledons through the soil surface.

Factors that can influence this stage (emergence) are planting date, planting depth, and soil factors such as soil temperature. Planting date can delay or accelerate emergence of sunflower seedlings. An early planting date may delay the emergence process but can be favourable for growth later in the season with a higher probability of more favourable moisture conditions (Soriano *et al*., 2004; Lawal *et al*., 2011). Late planting in sandy soils can lead to temperature stress during germination and emergence. Sandy soils can reach temperatures of 40°C and more during November to mid-January when planting commences. Poor emergence due to these conditions can cause uneven stand or result in re-planting (Nel, 2003; Anonymous, 2010).

Planting depth is another planting technique that can play a vital role during seedling establishment of sunflowers. Du Toit (1981) stated that ideal emergence is possible at a planting depth of 25-50 mm and planting depths of ≥50 mm causes delayed emergence. Generally sunflower is planted shallow (<30 mm) in clayish soil and deeper (≤80 mm) in sandy soils (Robinson, 1978), and, therefore, soil texture can also influence the decision of planting depth.

Inadequate planting techniques in combination with soil factors such as high soil temperatures (≥40°C) can ultimately lead to uneven and delayed emergence. All these factors should be considered during the planting season. The objective of this study was therefore to determine if planting techniques, such as planting date and planting depth, could affect seedling emergence of sunflower cultivars. Sunflower cultivars were also compared to determine possible differences in emergence rates of commercial sunflower cultivars.

4.2 Materials and Methods

4.2.1 Experimental Design

The experiments were conducted during September 2010, November 2010, and February 2011 in the glasshouses of the Department of Soil, Crop and Climate Science at the University of the Free State. Only South African commercially available cultivars were used (Table 4.1).

The experiment was laid out as a split plot design with four replications. The main plot in the split plot was planting depth with cultivar as the subplot. Treated seeds of eighteen cultivars (commercially available - Table 4.1) were planted at two planting depths (25 and 50 mm), at three planting dates (September and November 2010 and February 2011) and in two textured soils. The experiment was further conducted the same as described in Chapter 3, Section 3.2. The experimental lay out is given in Figure 4.1.

Table 4.1 Available commercial sunflower cultivars (seed size 3)

C1- AGSUN 5181	C7- DK 4040	C13- PAN 7050
C2- AGSUN 5264	C8- DKF 68-22	C14- PAN 7057
C3- AGSUN 5284	C9- NK ADAGIO	C15- PAN 7063
C4- AGSUN 5671	C10- NK ARMONI	C16- PAN 7351
C5- AGSUN 8251	C11- PAN 7033	C17- SY 4045
C6- CAP 4002	C12- PAN 7049	C18- SY 4200

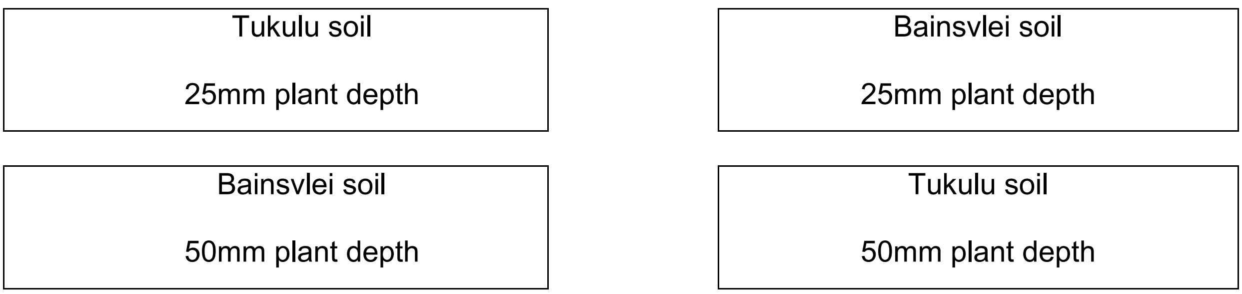


Figure 4.1 Experimental layout of the containers in the glasshouse with two planting depths and two soil types.

4.2.2 Parameters

Seedling emergence

The number of seedlings that emerged was recorded for 14 consecutive days. The appearance of the open cotyledons above the soil surface was an indication of emergence. Emergence percentages (E %) was determined by dividing the number of emerged seeds by the total number of seeds sown, multiplied by 100. Emergence index (EI), as modified and defined by Nel (1998a), was calculated as EI = $A_0 + A_1(0.95) + ... +A_6(0.45)$, where A is the percentage of hypocotyls that emerged from the soil. A_0 represented the day when emergence of cultivars (day 3 was used as a standard) commenced and A_6 represented day 9 after planting.

Plant height

Plant height was recorded for 10 randomly selected plants from each plot with termination of the experiment. Plant height per plant (mm) was measured from soil level to growing tips and finally the average plant height per plant was determined.

Fresh mass and dry mass

Fresh mass (g) of the 10 selected plants per cultivar was determined and oven dried at 50°C for 78 hours. The dry mass (g) of the plants was weighed and an average per plant determined.

Leaf area

Leaf area (cm^2) of 10 randomly selected plants was measured with a LI-COR 3100 leaf area meter and expressed on a per plant basis.

Statistical analysis

Data was analysed using the statistical program SAS 9.2® and means were separated using Tukey's Least Significant Difference test at the 5% probability level.

4.3 Results

The analyses of variance on sunflower cultivar response to planting date, -depth and soil texture are summarised in Table 4.1. Emergence index (EI) and plant height was significantly affected by cultivar for both soils for all three planting dates. Planting depth affected plant height, leaf area, and above ground dry mass significantly in the Tukulu soil for all planting dates. Leaf area of the Bainsvlei soil was also significantly affected by planting depth for all planting dates. Dry mass was significantly affected by both planting depth and cultivar during September and November 2010 in Bainsvlei soil (Table 4.1). Emergence index was significantly influenced by the planting depth by cultivar interaction during September 2010 in the Bainsvlei soil. Plant height (September 2010), leaf area, and dry mass (February 2011) was significantly influenced by the planting depth by cultivar interaction in the Tukulu soil (Table 4.1).

Table 4.1 Summary of the analyses of variance of treatment factors in the Bainsvlei and Tukulu soil form (PD = Planting depth; C = Cultivar)

Crop growth parameters	Factors	Bainsvlei soil			Tukulu soil		
		Sept 2010	Nov 2010	Feb 2011	Sept 2010	Nov 2010	Feb 2011
Emergence Index	Cultivar	*	*	*	*	*	*
	PD	*	ns	*	*	ns	*
	C x PD	*	ns	ns	ns	ns	ns
Plant height	Cultivar	*	*	*	*	*	*
	PD	*	ns	ns	*	*	*
	C x PD	ns	ns	ns	*	ns	ns
Leaf area	Cultivar	*	ns	ns	*	*	ns
	PD	*	*	*	*	*	*
	C x PD	ns	ns	ns	ns	ns	*
Dry mass	Cultivar	*	*	ns	*	ns	ns
	PD	*	*	ns	*	*	*
	C x PD	ns	ns	ns	ns	ns	*

* = significantly different, ns = not significant

4.3.1 Emergence and emergence index

4.3.1.1 Emergence

Cultivar emergence at 25 mm planting depth commenced at five days during September 2010, at four days during November 2010, and at three days during February 2011 after planting. Cultivar emergence at 50 mm planting depth commenced at seven days during September 2010, at five days during November 2010, and at four days during February 2011 after planting (results not shown).

4.3.1.2 Emergence index

Bainsvlei:

Emergence index (EI) was significantly affected by cultivars during November 2010 and February 2011 (Figure 4.1a). The EI of AGSUN 8251 and PAN 7033 was significantly higher than that of NK ARMONI, NK ADAGIO, DFK 68-22 and SY 4045 during November 2010. During February 2011 the EI of AGSUN 8251 was significantly higher than that of DK 4040, DKF 68-22, NK ARMONI and SY 4045 (Figure 4.1a). Emergence index of AGSUN 8251, PAN 7033, PAN 7351 and CAP 4002 was always above the mean for both planting dates. Conversely the EI of AGSUN 5282, DKF 68-22, NK ARMONI and SY 4045 was always below the mean for both planting dates (Figure 4.1a). Emergence index (EI) of sunflower in the Bainsvlei soil at 25 mm (Figure 4.2a) was significantly higher than at 50 mm during the February 2010 planting.

The September 2010 planting showed significant differences in EI through the interaction effect of cultivar and planting depth (Table 4.2). Emergence index of AGSUN 8251, PAN 7033, PAN 7351, PAN 7057, PAN 7049 and PAN 7050 was significantly higher than that of AGSUN 5264 and NK ARMONI at 25 mm planting depth. Emergence index of PAN 7050, AGSUN 8251, PAN 7033, PAN 7351 and AGSUN 5264 was significantly higher than that of AGSUN 5181, NK ADAGIO, SY 4200 and NK ARMONI at 50 mm planting depth. The EI of the majority of cultivars at 25 mm planting depth was significantly higher than that of the cultivars at 50 mm planting depth with the exception of PAN 7050, AGSUN 8251, PAN 7033 and PAN 7351. The EI of cultivars varied only with 15% or less between the two planting depths. Three of these cultivars (AGSUN 8251, PAN 7033 and PAN 7351) fall within the bracket of high EI (≥85%) and thus show good stability under the experimental conditions. The EI of NK ARMONI at 50 mm planting depth was the lower recorded EI (Table 4.2).

Tukulu:

Emergence index (EI) showed significant differences during all planting dates in the Tukulu soil for the selected cultivars (Figure 4.1b). Emergence index of AGSUN 8251, and PAN 7033 was significantly higher than that of SY 4045 and NK ARMONI for all the planting dates. During September 2010 and February 2011 the EI of DK 4040 and SY 4200 was also significantly lower than that of AGSUN 8251 and PAN 7033. Generally the EI of AGSUN 8251, PAN 7033, PAN 7049, PAN 7057 and PAN 7251 was always higher than the mean for all the planting dates while DK 4040 and NK ARMONI was always below the mean EI over cultivars (Figure 4.1b).

Emergence index showed significant differences between the planting depths in the Tukulu soil form during September 2010 and February 2011 (Figure 4.2b). At 25 mm planting depth EI was significantly higher than at 50 mm. The EI for the February 2011 planting was also significantly higher than that of the September 2010 planting (Figure 4.2b).

Comparing the results between the two soils evidently showed that the EI of AGSUN 8251 and PAN 7033 was significantly higher than that of NK ARMONI, DFK 68-22 and SY 4045 at all planting dates. Emergence index was also higher at 25 mm planting depth than at 50 mm for all the plantings for both soils.

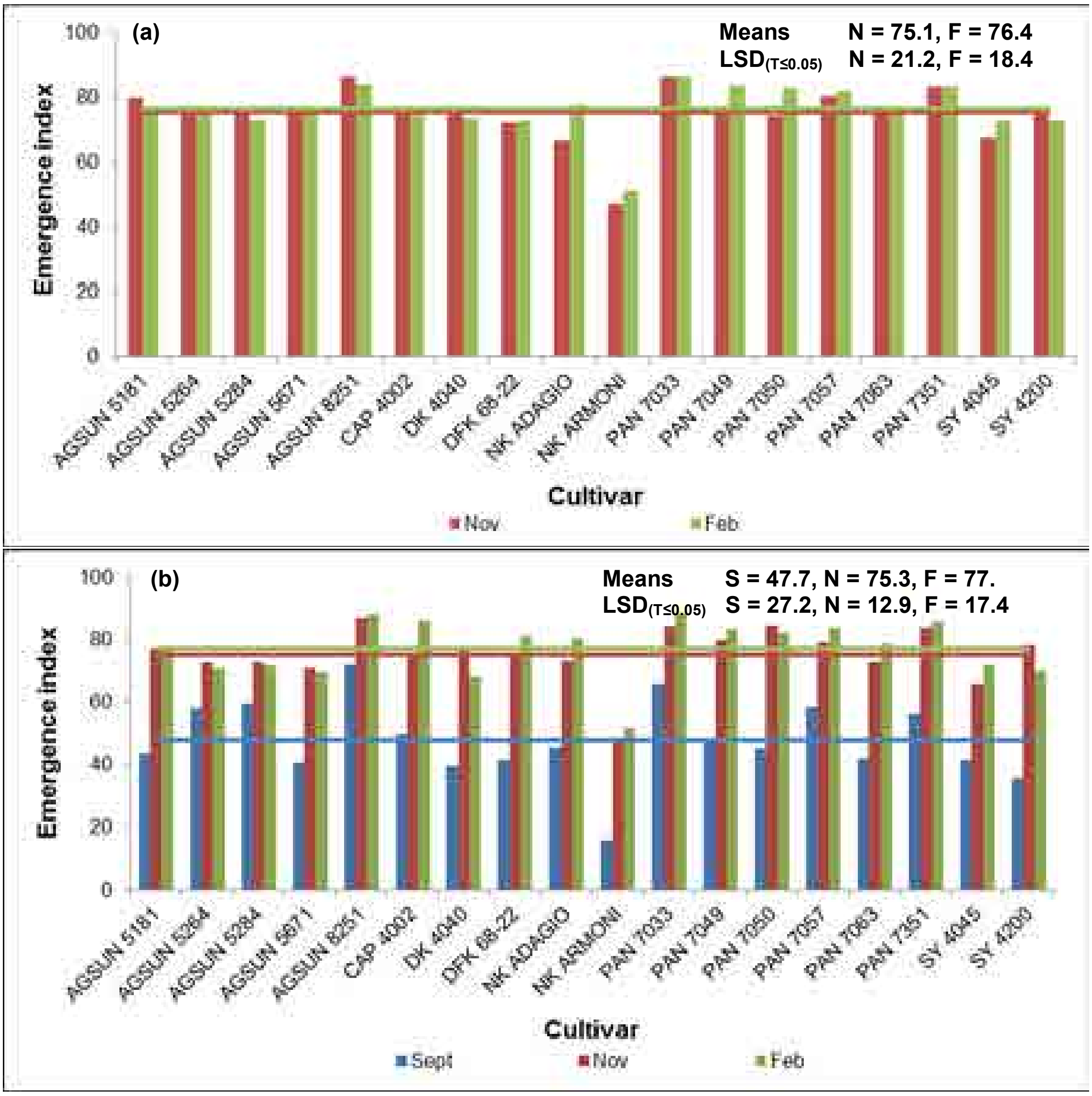


Figure 4.1 Emergence Index (EI) as affected by cultivar at different planting dates in (a) Bainsvlei soil and (b) Tukulu soil (S = September, N = November, F = Febuary).

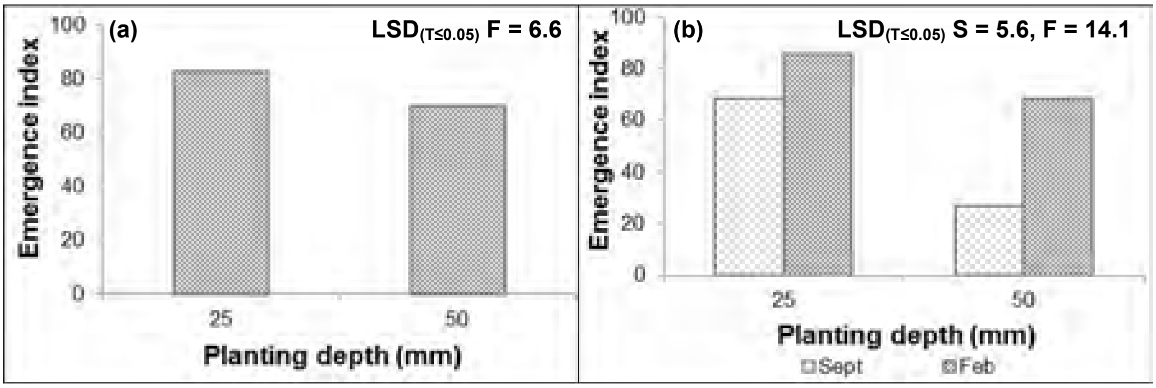


Figure 4.2 Emergence index (EI) as influenced by planting depth in (a) Bainsvlei and (b) Tukulu soil (S = September, F = February).

Table 4.2 Emergence index (EI) as affected by cultivar on two planting depths during September 2010 in Bainsvlei soil

Cultivar	Planting depth (mm)		
	25	50	Average
AGSUN 5181	65.83	31.82	**48.82**
AGSUN 5264	62.11	65.23	**63.67**
AGSUN 5284	72.74	52.83	**62.79**
AGSUN 5671	72.99	50.57	**61.78**
AGSUN 8251	86.27	72.34	**79.31**
CAP 4002	73.58	52.56	**63.07**
DK 4040	74.79	46.92	**60.86**
DKF 68-22	64.73	36.81	**50.77**
NK ADAGIO	72.74	28.49	**50.62**
NK ARMONI	54.25	1.167	**27.71**
PAN 7033	84.58	70.01	**77.30**
PAN 7049	79.08	47.23	**63.16**
PAN 7050	78.46	72.41	**75.44**
PAN 7057	81.49	51.00	**66.25**
PAN 7063	74.48	41.59	**58.04**
PAN 7351	85.91	69.75	**77.83**
SY 4045	67.17	32.99	**50.08**
SY 4200	72.64	25.75	**49.20**
Average	**73.55**	**47.19**	
$LSD_{(T\leq0.05)}$ C × PD = 22.25			

4.3.2 Plant Height

Plant height (mm) was recorded at termination of the experiment (21 days after plant).

Bainsvlei:

Significant differences in plant height were observed between the cultivars at all planting dates in the Bainsvlei soil. On average the tallest plants were recorded during November and the shortest plants during September. Plant height of PAN 7033 was significantly greater than NK ARMONI during September 2010 in the Bainsvlei soil. During November 2010 PAN 7033 and SY 4045 was significantly taller than CAP 4002. Plant height of PAN 7033 and SY 4045 was also significantly greater than that of CAP 4002 as well as NK ARMONI during February 2011 in the Bainsvlei soil (Figure 4.3a).

AGSUN 5264, PAN 7033, PAN 7057, PAN 7063, PAN 7351 and SY 4045 were all consistently greater than the average plant height calculated at all planting dates in the Bainsvlei soil. In contrast AGSUN 5254, AGSUN 8251 as well as CAP 4002 and NK ARMONI were all shorter than the average plant height at all planting dates. All other remaining cultivars showed inconsistent results at the specific planting dates (Figure 4.3a).

Tukulu:

Plant height of AGSUN 8251, PAN 7033, PAN 7063 and SY 4045 was significantly greater than AGSUN 8251, CAP 4002 and NK ARMONI during September 2010 in the Tukulu soil (Figure 4.3b). During November 2010 the plant height of SY 4045 was significantly greater than AGSUN 8251 and NK ARMONI. Plant height of PAN 7057, PAN 7063, PAN 7351 and SY 4045 was significantly greater than that of AGSUN 8251 and CAP 4002 during February 2011 in the Tukulu soil. Plant height of PAN 7033, PAN 7049, PAN 7057, PAN 7063, PAN 7351 and SY 4045 were consistently taller than the average plant height calculated at all planting dates in the Tukulu soil. Conversely AGSUN 5284, AGSUN 8251, CAP 4002, DK 4040 and NK ARMONI were shorter than the calculated average plant height at all the planting dates. Inconsistent results were obtained for the plant height of the remaining cultivars at all the planting dates in the Tukulu soil (Figure 4.3b).

Comparing results obtained from the two soils it was evident that AGSUN 5284, AGSUN 8251, CAP 4002 and NK ARMONI obtained below average plant heights at all planting dates as compared to PAN 7033, PAN 7057, PAN 7063, PAN 7351 and SY 4045 that were taller than the average plant height at the corresponding planting dates.

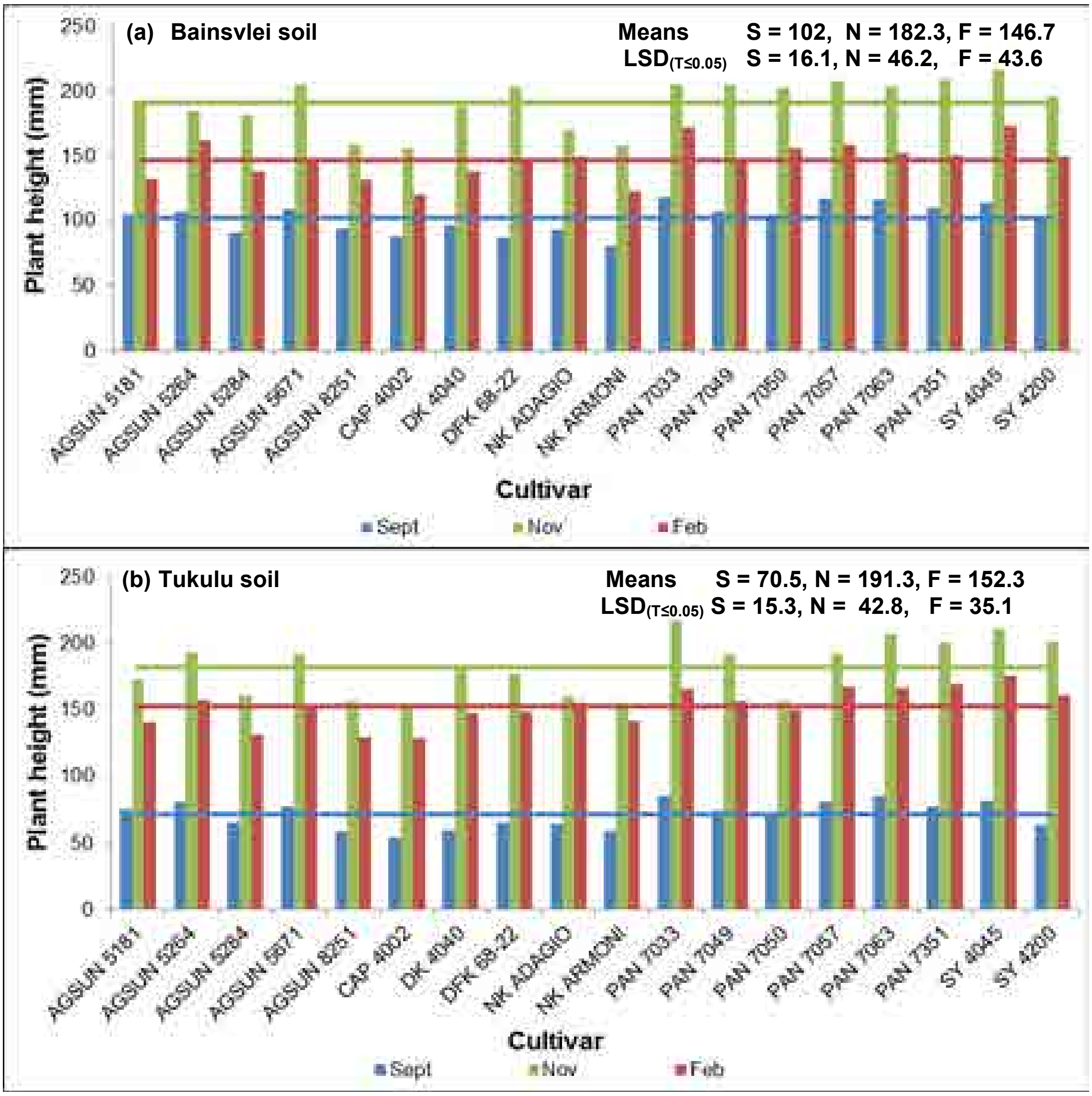


Figure 4.3 Plant height of different cultivars at three different planting dates in (a) Bainsvlei and (b) Tukulu soil (S = September, N = November, F = February).

Plant height was not significantly influenced by planting depth in the Bainsvlei soil for all planting dates. In the Tukulu soil (higher clay content) plant height was significantly affected (Figure 4.4). Plant height of plants planted in November 2010 was greater than that of plants planted in September 2010 or February 2011. The plant height of plants planted at a planting depth of 25 mm (145.93 mm) was significantly greater compared to that planted at 50 mm (124.15 mm).

There was a significant interaction between cultivar and planting depth in the Tukulu soil during September 2010 (Table 4.3). Plant height of PAN 7063 and PAN 7033 and SY 4200 at 25 mm planting depth was significantly greater than that of SY 4200 and CAP 4002 at the same planting depth. Plant height of PAN 7057, PAN 7033 and AGSUN 5264 was significantly greater than the plant height of NK ARMONI and AGSUN 8251 at 50 mm planting depth. The majority of cultivars at 25 mm planting depth were significantly taller than the same cultivar at 50 mm planting depth with the exception of cultivars CAP 4002, DK 4040, DKF 68-22 and SY 4200 (Table 4.3).

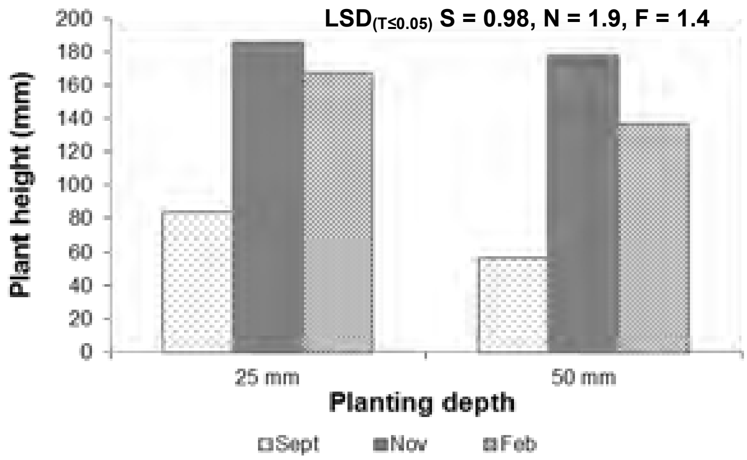


Figure 4.4 Plant height as influenced by planting depth in Tukulu soil (S = September, N = November, F = February).

Table 4.3 Plant height (mm) of different cultivars in Tukulu soil at two different planting depths during September 2010

Cultivar	Planting depth (mm)		
	25	50	Average
AGSUN 5181	88.83	60.40	**74.61**
AGSUN 5264	92.78	67.15	**79.96**
AGSUN 5284	77.90	51.13	**64.51**
AGSUN 5671	92.23	60.05	**76.14**
AGSUN 8251	73.28	44.93	**59.10**
CAP 4002	60.68	47.60	**54.14**
DK 4040	69.45	49.33	**59.39**
DKF 68-22	75.20	53.40	**64.30**
NK ADAGIO	78.08	49.00	**63.54**
NK ARMONI	71.70	45.28	**58.49**
PAN 7033	102.65	67.30	**84.98**
PAN 7049	93.83	53.55	**73.69**
PAN 7050	87.73	55.78	**71.75**
PAN 7057	91.70	68.15	**79.93**
PAN 7063	108.18	61.80	**84.99**
PAN 7351	89.18	63.98	**76.57**
SY 4045	94.80	66.75	**80.78**
SY 4200	69.43	56.25	**62.84**
Average	**84.31**	**56.77**	

$LSD_{(T \leq 0.05)}$ C × SD = 15.75

4.3.3 Leaf Area

Significant differences were recorded in leaf area for cultivars at all planting dates on both the Bainsvlei and Tukulu soil. The smallest average leaf area of all cultivars was recorded during September 2010 in the Tukulu soil and November 2010 in the Bainsvlei soil (Figure 4.5a & b). Leaf area was measured with termination of the experiment (21 days after plant).

Bainsvlei:

Leaf area of AGSUN 5264 was significantly greater than NK ARMONI during September 2010 and February 2011 on the Bainsvlei soil. AGSUN 5264 also indicated a significant greater leaf area than CAP 4002 and PAN 7050 during November 2010 on the specific soil. The recorded leaf area of AGSUN 5264, PAN 7033 and SY 4045 was greater than the average during all planting dates in the Bainsvlei soil. The leaf area of all other cultivars showed inconsistent results during all planting dates in the Bainsvlei soil (Figure 4.5a).

Tukulu:

Leaf area of AGSUN 5264 was significantly greater than that of DK 4040 (September 2010) and NK ARMONI (November 2010) on the Tukulu soil. PAN 7033 showed a significantly greater leaf area than cultivar DK 4040, NK ADAGIO and NK ARMONI during February 2011 in the Tukulu soil. The leaf area of AGSUN 5264, AGSUN 5671, PAN 7033, PAN 7063 and SY 4045 were greater than the calculated average leaf area during all planting dates in the Tukulu soil (Figure 4.5b). Cultivars that showed a smaller recorded leaf area than the average were AGSUN 5284, DK 4040, DKF 68-22, NK ADAGIO, NK ARMONI and PAN 7049 during all planting dates on both soils (Figure 4.5)

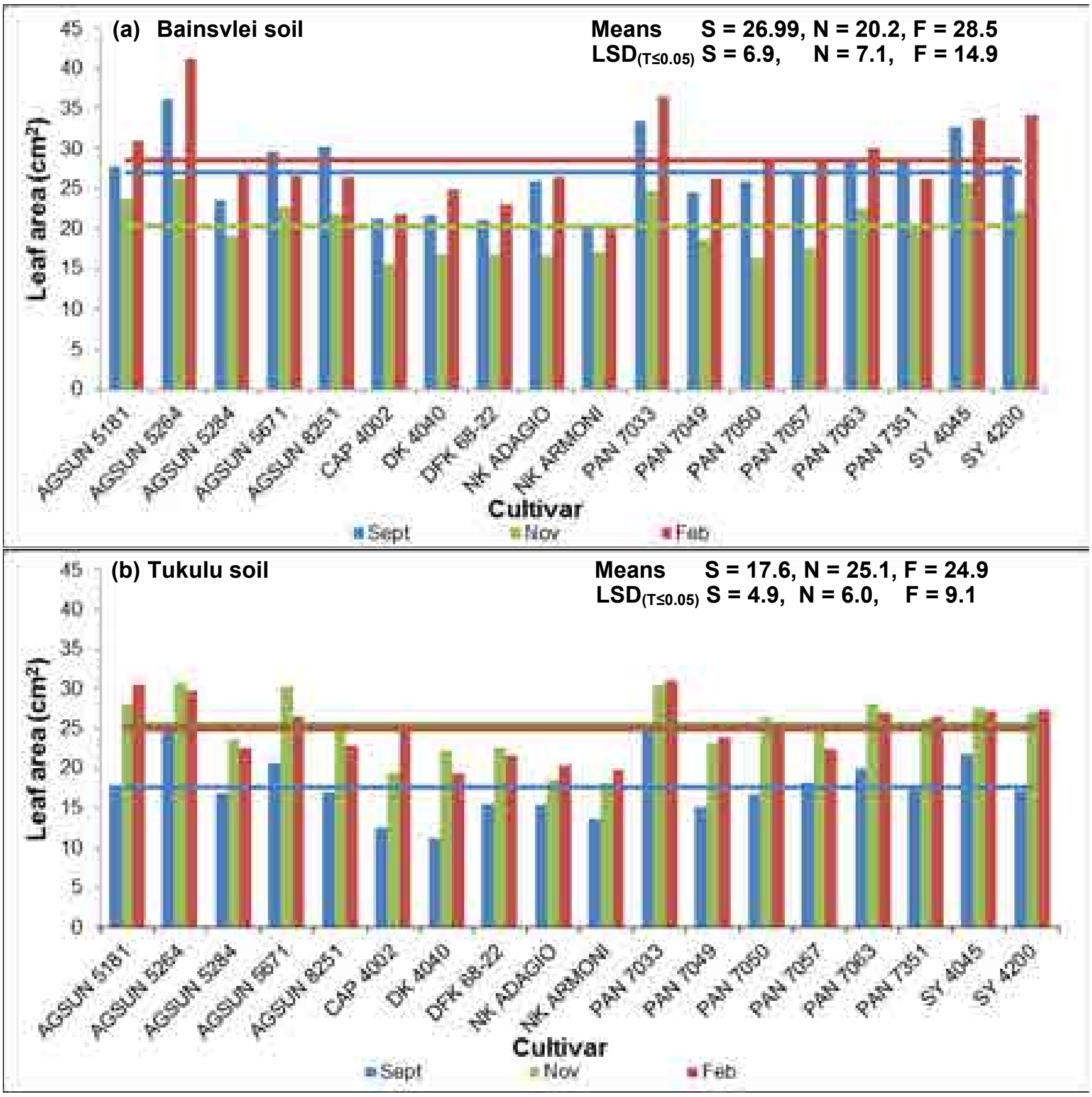


Figure 4.5 Leaf area as affected by cultivar at three different planting dates in (a) Bainsvlei and (b) Tukulu soil (S = September, N = November, F = February).

Leaf area was significantly affected by planting depth alone during November 2010 on the Bainsvlei soil and during September and November 2010 on the Tukulu soil (Figure 4.6). In all instances the 25 mm planting depth produced the greatest leaf area. The reason for this is obvious and will be dealt with in the discussion.

The only significant treatment combination (cultivar by planting depth) affecting leaf area was found during February 2011 on the heavier Tukulu soil (Table 4.4). The greatest leaf area was measured for AGSUN 5181 at a planting depth of 50 mm. Although this was the treatment combination that produced the greatest leaf area it did not differ significantly from 17 other treatment combinations. The significant smallest leaf area (17.5 cm^2) was found for the treatment combination of DK 4040 planted at 25 mm. This leaf area was, though the smallest, not significant smaller than 26 other treatment combinations (Table 4.4).

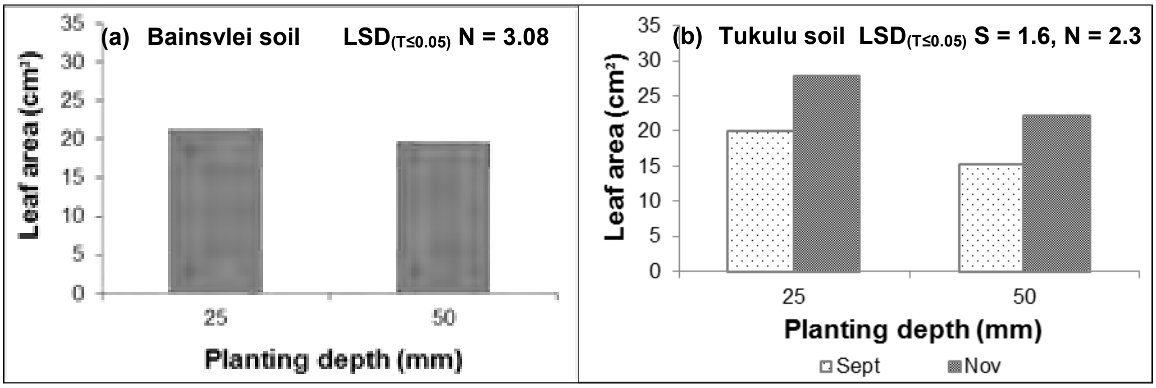


Figure 4.6 Leaf area as affected by planting depth in (a) Bainsvlei (November) and (b) Tukulu soil (S = September, N = November).

Table 4.4: Leaf area (cm^2) as affected by cultivar in Tukulu soil at two different planting depths during February 2011

Cultivar	Planting depth (mm)		
	25	50	Average
AGSUN 5181	25.1425	35.9983	**30.5704**
AGSUN 5264	33.5718	25.8085	**29.6901**
AGSUN 5284	19.7657	25.2447	**22.5052**
AGSUN 5671	26.8984	26.1387	**26.5185**
AGSUN 8251	23.0369	22.5667	**22.8018**
CAP 4002	22.6387	28.5092	**25.5739**
DK 4040	17.4738	20.9099	**19.1918**
DKF 68-22	21.5896	21.5890	**21.5893**
NK ADAGIO	21.7684	18.9647	**20.3665**
NK ARMONI	22.4162	16.9314	**19.6738**
PAN 7033	29.4037	32.7102	**31.0569**
PAN 7049	27.5987	20.1567	**23.8777**
PAN 7050	24.8080	24.3982	**24.6031**
PAN 7057	23.5777	20.9872	**22.2824**
PAN 7063	26.8240	27.0680	**26.946**
PAN 7351	25.3135	27.8477	**26.5806**
SY 4045	29.4925	24.6800	**27.0862**
SY 4200	26.3445	28.3790	**27.3617**
Average	**24.8703**	**24.9382**	
$LSD_{(T \leq 0.05)}$	C × SD = 9.3276		

4.3.4 Dry Mass

Bainsvlei:

Dry mass indicated significant differences during September and November 2010 on the Bainsvlei soil. Dry mass was greater than the calculated average for AGSUN 5164, AGSUN 5671, PAN 7033, PAN 7063, SY 4045 and SY 4200 during September and November 2010 in the Bainsvlei soil (Figure 4.7a). SY 4045 indicated a significant greater dry mass than NK ARMONI (September 2010) and CAP 4002 and DK 4040 (November 2010) in the Bainsvlei soil (Figure 4.7a).

Tukulu:

Dry mass indicated significant differences during September and November 2010, and February 2011 on the Tukulu soil (Figure 4.7b). Dry mass was greater than the average during September, November 2010 and February 2011 for AGSUN 5261, AGSUN 5671, PAN 7033, PAN 7063, PAN 7351 and SY 4045 (Figure 4.7b). The dry mass of PAN 7033 was significantly greater than that of CAP 4002, NK ADAGIO and NK ARMONI during November 2010. On the other hand dry mass of AGSUN 5264 was significantly greater than that of CAP 4002 (September 2010), AGSUN 5284 and NK ARMONI (February 2010). Remaining cultivars showed inconsistent results for the spesific planting dates (Figure 4.7a & b).

Dry mass of AGSUN 5264, AGSUN 5671, NK ARMONI, PAN 7063 and SY 4045 were consistently greater than the calculated average on both soils for all planting dates while the dry mass of AGSUN 5284, AGSUN 8251, CAP 4002, DK 4040, DKF 68-22, NK ADAGIO, NK ARMONI, PAN 7049 were smaller than the calculated average on both soils for all planting dates (Figure 4.7).

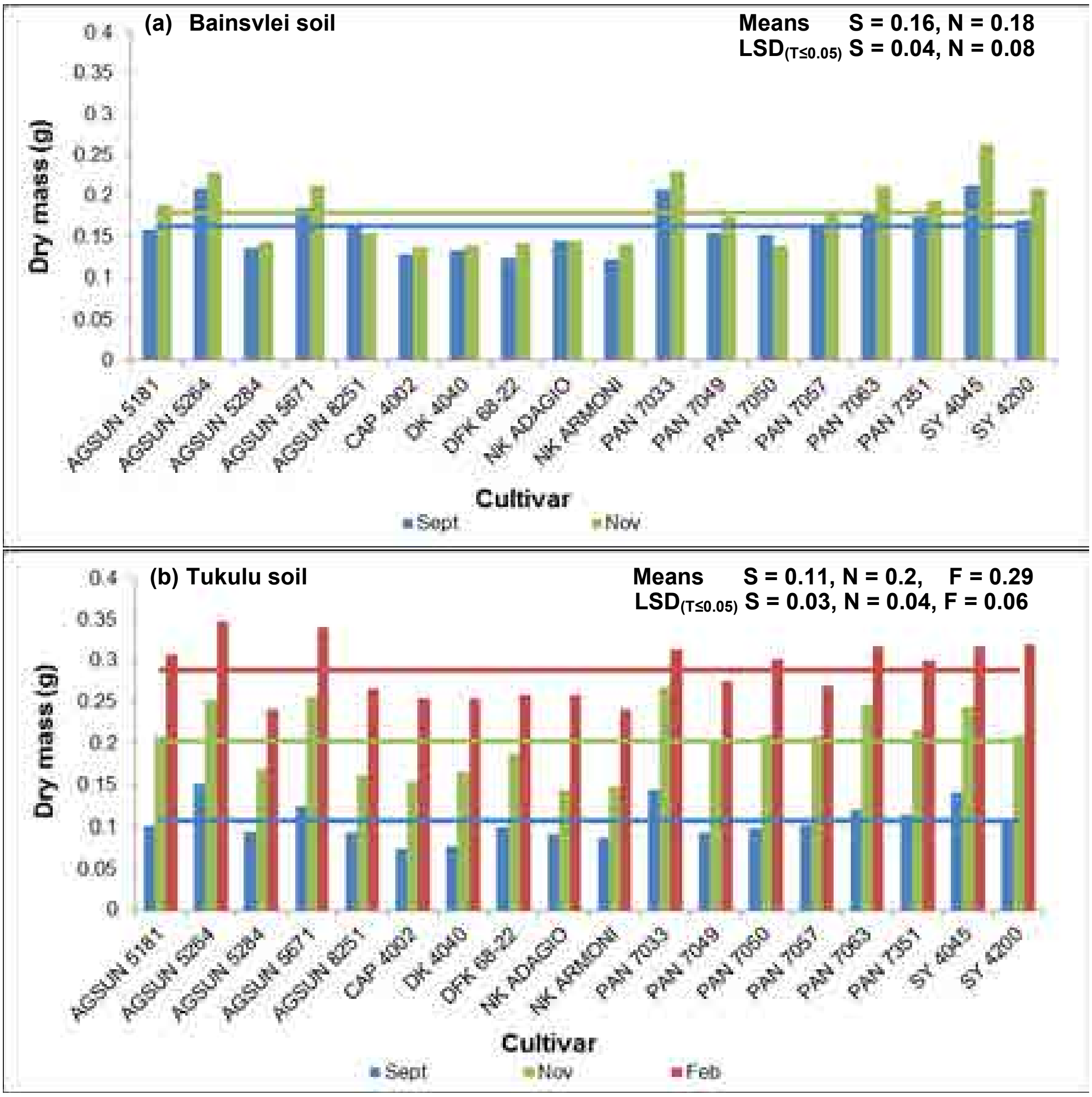


Figure 4.7 Dry mass as affected by cultivar at three different planting dates in (a) Bainsvlei and (b) Tukulu soil (S = September, N = November, F = February).

Both September and November 2010 planting dates showed that planting depth significantly affected the dry mass produced in the Bainsvlei soil (Figure 4.8a). Similar results were obtained in the Tukulu soil, but only for the September 2010 planting date (Figure 4.8b). All three instances showed that the 25 mm planting depth resulted in the significant greatest dry mass acquired.

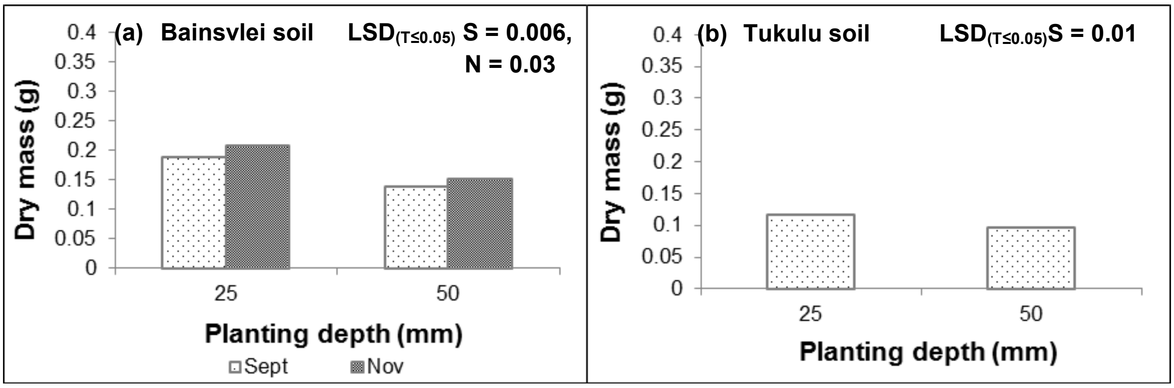


Figure 4.8 Dry mass as affected by planting depth in (a) Bainsvlei and (b) Tukulu soil (S = September, N = November).

Similarly to leaf area, dry mass responded significantly to the treatment combination of cultivar by planting depth during February 2011 (Table 4.5). The dry mass of AGSUN 5671 was the greatest at a planting depth of 50 mm and it was significantly greater than at 25 mm planting depth. The smallest dry mass was determined for NK ARMONI at 50 mm planting depth and it was significantly smaller than at 25 mm planting depth (Table 4.5).

Table 4.5: Dry mass (g) as affected by cultivar in Tukulu soil at two different planting depths during February 2011

Cultivar	Planting depth (mm)		
	25	50	Average
AGSUN 5181	0.291	0.326	**0.308**
AGSUN 5264	0.337	0.358	**0.348**
AGSUN 5284	0.251	0.232	**0.241**
AGSUN 5671	0.304	0.376	**0.340**
AGSUN 8251	0.237	0.296	**0.266**
CAP 4002	0.273	0.237	**0.255**
DK 4040	0.237	0.272	**0.255**
DKF 68-22	0.256	0.262	**0.259**
NK ADAGIO	0.261	0.258	**0.259**
NK ARMONI	0.290	0.194	**0.242**
PAN 7033	0.279	0.348	**0.313**
PAN 7049	0.275	0.276	**0.276**
PAN 7050	0.275	0.328	**0.301**
PAN 7057	0.275	0.262	**0.269**
PAN 7063	0.315	0.319	**0.317**
PAN 7351	0.292	0.310	**0.300**
SY 4045	0.337	0.297	**0.317**
SY 4200	0.278	0.361	**0.319**
Average	**0.281**	**0.295**	
$LSD_{(T\leq0.05)}$	C×SD = 0.067		

4.4 Discussion

Castiglioni *et al.* (1994) as cited by Albuquerque & de Carvalho (2003) state that emergence under normal conditions should occur within seven days of planting. Emergence of sunflowers commenced within the first seven days after planting with a faster emergence on the lighter Bainsvlei soil than on the heavier Tukulu soil. Emergence at 25 mm planting depth commenced within 5 days after planting while emergence at 50 mm planting depth commenced within 7 days after planting which concurs with the findings of Castiglioni *et al.* (1994) as cited by Albuquerque & de Carvalho (2003). Emergence at 25 mm planting depth was therefore faster for both soils at all the planting dates when compared to emergence at 50 mm planting depth. This indicates that sunflower emergence was delayed with an increase in planting depth (Berti *et al.,* 2008; Albuquerque & de Carvalho, 2003).

Emergence index of AGSUN 8251 was consistently greater than that of the other cultivars during all the planting dates at all treatments. NK ARMONI showed a smaller emergence index during all the planting dates for all treatments. Both soil temperature and soil moisture can influence emergence (Helms *et al*., 1997). With a rise in the soil temperature it was observed that the soil dried faster and water had to be applied more frequently during the experiment period to ensure emergence and avoid drought stress. The Bainsvlei soil has a lower clay content than the Tukulu soil (Chimungu, 2009), therefore the bonds between water and soil particles are stronger in the Tukulu soil than the Bainsvlei soil (Connolly, 1998). It was observed that the Tukulu soil stayed longer moist causing the soil to stay cool longer. Cooler soil conditions can cause delayed emergence or a slower emergence rate which was observed on the Tukulu soil at 50 mm planting depth. The fastest emergence rate was observed with AGSUN 8251 during September and November 2010 reaching 100% emergence within 7-10 days after planting. During February 2011 this cultivar had a slower emergence rate except on the Tukulu soil at 50mm planting depth. The slowest emergence rate was observed for NK ARMONI at all the treatment combinations.

Cultivars tested in this experiment were all generally taller during the November 2010 planting for both soils compared to other planting dates with higher recorded plant heights at 25 mm planting depth than 50 mm planting depth. Leaf area was the greatest during February 2011 on both soils at 25 mm planting depth. The smallest average leaf area in the Bainsvlei soil was recorded during November 2010 and in the Tukulu soil during September 2010. The average dry mass was the greatest during February 2011 on both soils with the lowest recorded dry mass for cultivars during September 2010. Dry mass averages were greater at 25 mm planting depth than at 50mm planting depth except during February 2011 in the Tukulu soil where the dry mass was higher at 50mm planting depth than at 25 mm planting depth. Sharratt & Gesch (2004) report that above ground growth (biomass) of crops may decrease with a delay in planting date but this experiment indicated that delayed planting dates can also improve above ground growth which is all known to be temperature dependent.

Comparing the different plant parameters at 25 and 50 mm planting depth, the measurements at the latter planting depth were smaller than that planted at 25 mm but during February 2011 the converse was observed. Plant height (29.05 mm) and leaf area (3.37 cm^2) was lower at 25 mm planting depth than at 50 mm planting depth. This may have been caused by the seedling disease that was observed in the soil during February 2011. The soil and plant material was analysed and several pathogens was detected in the soil. These pathogens were *Alternaria* sp, *Fusarium* sp and *Rhizopus oryzae.* Damage by seedling diseases was more prominent in the Bainsvlei soil at 25 mm planting depth than in the Tukulu soil at 50 mm planting depth. The Bainsvlei soil dried quicker than the Tukulu soil and during February 2011 the soil dried even faster causing the top soil to form a crust. To prevent encrustation water was applied more frequently to keep the top soil moist. Higher temperatures and moist conditions realised a higher humidity and therefore caused the ideal conditions for pathogen infection.

4.5 Conclusion

Seedling emergence is dependent on different factors such as cultivar, planting date and planting depth. Temperature (air and soil) play a vital role in sunflower production and therefore the planting date is extremely important. Depending on the soil conditions it is better to plant during a time when the first 7 days of emergence falls within the optimum range (27-28°C) of soil temperature for sunflower production. This will lead to a greater emergence percentage that may lead to a greater and acceptable stand. Problems were identified during this experiment with the temperature range. Expected high temperatures were not reached in the soil due to higher rainfall and cloudiness with low radiation during January and February 2011. Plant diseases were also evident during the last planting date. The technique was therefore refined for the second experiment (Chapter 5) to prevent any unexpected climate changes.

CHAPTER 5

EMERGENCE RESPONSE OF SUNFLOWER CULTIVARS (*Helianthus annuus* L.) TO HIGH SOIL TEMPERATURES

5.1 Introduction

Emergence of sunflower in sandy soils has proven to be a problem during November to late January in the Free State and North West provinces. Top soil temperatures easily exceed 43°C in these sandy soils and cause poor emergence rates of sunflower seedlings (Nel, 1998a & 1998b). High temperatures in the top soil can cause stress to the hypocotyls responsible for the emergence of the cotyledons above the soil surface.

Soil temperature is expected to be lower than air temperature during the growing season, with the exception of the surface soil layer, 0-50 mm (De Villiers, 2007). This layer of soil is generally warmer and fluctuations are common in this layer. Germination and emergence occur in this layer and are therefore subjected to these fluctuations in soil temperature (Nielsen, 1974). The majority of sunflower roots occur in the top 400 mm of soil. Roots are sensitive organs and are less adaptive to temperature fluctuations (Nielsen, 1974). Both root and hypocotyl elongation can increase with an increase in temperature until temperature reaches the optimum of 25°C. Soil temperatures above 35°C may reduce metabolic activities and inhibit root elongation (McMichael & Quisenberry, 1993; Seiler 1998). Root and hypocotyls elongation is known decreases when temperature exceeds the lethal threshold temperature of 45°C (Gay *et al*., 1991).

Most enzyme activities are inactive at temperatures of 40 to 45°C, and this causes a decrease in the germination process. Germination can take place at 40°C, but root and hypocotyl growth will be inhibited, and complete inhibition of germination and growth will take place at 45°C (Gay *et al*., 1991). Temperatures above the optimum can therefore lead to uneven and unsuccessful sunflower stand. The objective of this experiment is to determine the effect of temperature (above the optimum) and different cultivars on the emergence, above ground and root growth of sunflower seedlings.

5.2 Materials and Methods

5.2.1 Experimental design

An experiment was conducted at the Department of Soil, Crop and Climate Sciences of the University of the Free State. Cultivars of seed size three were chosen from the previous experiment (Table 5.1.).

Table 5.1 Available sunflower cultivars

C1- PAN 7033	C5- AGSUN 8251
C2- PAN 7049	C6- AGSUN 5264
C3- PAN 7050	C7- AGSUN 5671
C4- PAN 7057	

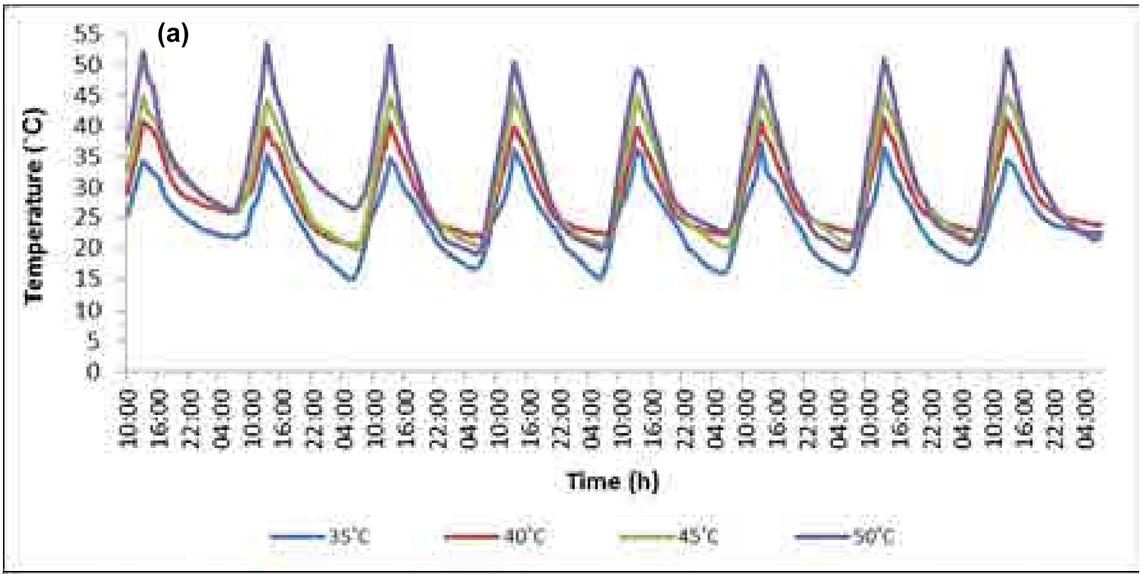
The experimental design as described in Chapter 3 and 4 was repeated with the exception of planting depth and soil type. Differences between planting depth and soil texture were discussed in Chapters 3 and 4, and therefore the study was conducted at a planting depth of 25 mm on the Bainsvlei top soil. Four soil temperature treatments, namely 35, 40, 45 and 50°C, were applied. Soil was watered according to the drained upper limit (DUL), which would be the same as described in Chapter 3 and 4 for the Bainsvlei soil (Chaper 3, Section 3.2). Only two containers were used with each temperature range of which one container was used for destructive measurements. The containers were painted on the inside with water proof rubberising paint to prevent water leakage. Aluminium foil was lined on the outside of the containers to prevent heat absorption through radiation. Seven commercially available cultivars were used for this experiment (Table 5.1). The experiment was also repeated (planting one and two).

A metal galvanised mesh divided in blocks of 50×50 mm was placed on the planting level in the containers. A single seed was placed in each block (50×50 mm) with a total of 25 seeds for each cultivar. A second layer of soil (15 mm) was used to cover the seeds and this was wet according to the DUL. Finally dry soil (10 mm) was placed on top to prevent encrustation. The grid was cross wired with an under floor heating wire (23kW) enabling the heating of the soil up to 55°C (Figure 5.1). Soil temperature was therefore controllable and could be set to the desired temperature.

Figure 5.1 The grid used to heat soil with a computer program in containers (a – c).

The grid was connected to a computer program that simulated day/night temperatures in the soil to reach the desired temperatures (Figure 5.2). The programming was based on data collected from the field, which indicates that soil temperatures can reach 52°C during the day and fall to 15°C during the night (A.A. Nel, personal communication[1]). Soil moisture was monitored hourly at 25 mm planting depth with ECH_2O data loggers. The day/night temperatures were monitored at 25 mm and 10 mm with Hobo channel loggers at hourly intervals (Figure 5.2).

[1] Dr A.A. Nel, 2011. ARC – Grain Crops Institute, Private Bag X1251, Potchefstroom 2520



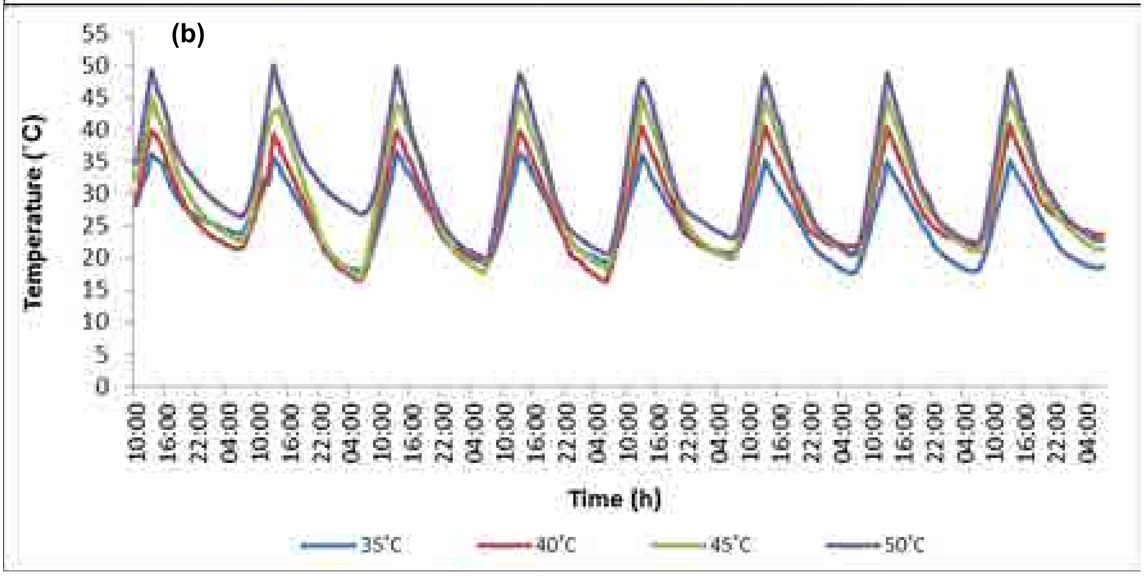


Figure 5.2 Simulated soil temperatures at 35, 40, 45 and 50°C at 10 mm (a) and 25 mm (b) depths as measured with Hobo channel loggers for the experimental period.

5.2.2 Parameters

Seedling emergence

Seedling emergence was determined as described in Chapter 3 and 4 and was recorded for 10 days only. Emergence index (EI) was also calculated with the same formula used in Chapter 3, Section 3.2.2.

Root length

Root length (mm) of the tap root was measured by extracting five randomly selected plants 24 hours after planting, with first emergence and 48 hours after first emergence. First emergence can be defined as the cracking of the soil surface by the protrusion of the hypocotyls.

Seedling height

Seedling height was recorded for 20 randomly selected plants from each plot with the termination of the experiment. Seedling height per plant was measured in mm from soil level to growing tips and finally the average seedling height per plant was determined.

Fresh mass and dry mass

Fresh mass (g) of the 20 selected plants per cultivar was also determined and oven dried at 50°C for 7 days with termination of the experiment. The dry mass (g) of the plants was weighed and an average per plant determined.

Morphology

Visual morphological differences of hypocotyl and root appearance were captured photographically and will be discussed. These observations were made with every root extraction date.

Statistical analysis

Data was analysed using the statistical program SAS 9.2® and means were separated using Tukey's Least Significant Difference test at the 5% probability level.

5.3 Results

The analysis of variance on sunflower response to soil temperature and different cultivars are summarised in Table 5.2. Emergence index and root length 24 h after planting was significantly affected by the interaction treatment of temperature by cultivar for both plantings. All other parameters were significantly influenced by temperature during both plantings. The effect of cultivar on plant height, fresh and dry mass was also significant for both plantings.

Table 5.2 Summary of the analysis of variance of treatment factors of planting one and two

Crop growth parameters	Factors	Planting 1	Planting 2
Emergence index (EI)	Temperature	*	*
	Cultivar	ns	*
	Temp x Cult	*	*
Plant height	Temperature	*	*
	Cultivar	*	*
	Temp x Cult	ns	ns
Fresh mass	Temperature	*	*
	Cultivar	*	*
	Temp x Cult	ns	ns
Dry mass	Temperature	*	*
	Cultivar	*	*
	Temp x Cult	ns	ns
Root length 24h after plant	Temperature	*	*
	Cultivar	*	*
	Temp x Cult	*	*
Root length with surface Crack	Temperature	*	*
	Cultivar	ns	ns
	Temp x Cult	ns	ns
Root length 48h after surface crack	Temperature	*	*
	Cultivar	ns	ns
	Temp x Cult	ns	ns

* = significantly different
ns = not significant

5.3.1 Emergence index

Emergence index (EI) was significantly influenced by the temperature and cultivar interaction at planting one (Table 5.3). Emergence index of all cultivars at 35 and 40°C was significantly higher than that of cultivars at 45 and 50°C with the exception of AGSUN 8251, AGSUN 5264 and PAN 7033 at 45°C. All cultivars showed a moderate decreasing tendency in EI from 35 to 45°C, but from 45°C to 50°C this decrease was extreme. The EI of some cultivars declined significantly while other cultivars did not (Table 5.3). Since it's known that the critical supra-optimal temperature is 43°C (Nel, 1998a & 1998b) it was now confirmed that new cultivars 15 years later still react the same

Table 5.3 Emergence index (EI) as affected by cultivar at four temperature treatments during the first planting

Cultivar	Temperature (°C)				Average
	35	**40**	**45**	**50**	
AGSUN 8251	96.75	94.40	88.20	7.050	**71.60**
AGSUN 5264	92.70	88.40	82.30	7.750	**67.79**
AGSUN 5671	90.65	88.65	50.15	16.05	**61.38**
PAN 7033	93.95	92.70	76.60	5.100	**67.09**
PAN 7049	91.20	88.10	70.90	5.150	**63.84**
PAN 7050	89.50	94.55	67.65	2.550	**63.57**
PAN 7057	87.25	90.15	67.15	5.050	**62.40**
Average	**91.71**	**90.99**	**71.85**	**6.957**	
$LSD_{(T \leq 0.05)}$ C × T = 18.3					

Emergence index (EI) was also significantly affected by the interaction of temperature and cultivar at the second planting (Table 5.4). Emergence index of all the cultivars at 35, 40 and 45°C was significantly higher than that of 50°C with the exception of AGSUN 5671 at 45°C (Table 5.4). Similar tendencies were observed during planting two compared to planting one. Though the decrease in EI at 50°C was also severe it was not as extreme as that of planting one.

Table 5.4 Emergence index (EI) as affected by cultivar at four temperature treatments during the second planting

Cultivar	Temperature (°C)				Average
	35	**40**	**45**	**50**	
AGSUN 8251	94.65	94.50	92.55	22.20	**75.98**
AGSUN 5264	93.45	88.95	84.75	38.15	**76.33**
AGSUN 5671	90.95	87.00	34.25	23.95	**59.04**
PAN 7033	91.95	93.05	80.55	8.600	**68.54**
PAN 7049	84.80	90.65	88.70	19.60	**70.94**
PAN 7050	86.60	85.50	75.55	13.95	**65.40**
PAN 7057	93.20	93.00	86.80	25.90	**74.73**
Average	**90.80**	**90.38**	**77.59**	**21.76**	
$LSD_{(T \leq 0.05)}$ C × T = 27.0					

5.3.2 Root length

Root length of seedlings was significantly influenced by the treatments as follow: 24 hours after plant root length was significantly influenced and the temperature by cultivar interaction at both plantings, while surface crack and 48 hours after surface crack root length was only significantly influenced by temperature at both plantings. Root length 24 hours after plant obtained inconsistent results between the two plantings with no definite repeated combinations of temperature and cultivar interactions that influenced the root length (Table 5.5 & 5.6). Results from root length with surface crack and 48 hours after surface crack indicated that root length at 35°C was significantly longer than that at 45 and 50°C (Figure 5.3 & 5.4).

5.3.2.1 Root length 24 hours after plant

Root length of seedlings 24 hours after plant was significantly influenced by the temperature and cultivar interaction at planting one (Table 5.5). The root length of AGSUN 5264, AGSUN 5671 and PAN 7057 at 35°C and PAN 7057 at 40°C was significantly longer than PAN 7033 at 35, 45 and 50°C; AGSUN 5671 at 40, 45 and 50°C; PAN 7049 at 40, 45 and 50°C; AGSUN 8251, AGSUN 5264 and PAN 7050 at 45 and 50°C as well as PAN 7057 at 45°C (Table 5.5).

Table 5.5 Root length (mm) as affected by temperature by cultivar interaction during the first planting

Cultivar	Temperature (°C)				Average
	35	40	45	50	
AGSUN 8251	2.127	5.015	2.044	3.567	**3.188**
AGSUN 5264	9.543	6.537	2.991	4.535	**5.902**
AGSUN 5671	7.395	4.500	1.351	4.314	**4.390**
PAN 7033	4.545	5.120	2.102	4.635	**4.101**
PAN 7049	5.420	4.895	2.288	4.103	**4.176**
PAN 7050	4.960	6.399	2.437	3.084	**4.220**
PAN 7057	7.402	7.734	3.590	5.752	**6.119**
Average	**5.913**	**5.743**	**2.400**	**4.284**	
$LSD_{(T \leq 0.05)}$ C × T = 2.5					

Root length 24 hours after planting was also significantly influenced by the temperature and cultivar interaction during the second planting (Table 5.6). The root length of AGSUN 5264, PAN 7049, PAN 7050 and PAN 7057 at 40°C was significantly longer than that of AGSUN 8251, AGSUN 5264, PAN 7033, PAN 7049 and PAN 7050 at 35, 45 and 50°C as well as AGSUN 5671 at all temperature treatments and PAN 7057 at 50°C at the second planting (Table 5.6). Root length 24 hours after plant of PAN 7057 at 40°C was longer than most of the treatment combinations at both plantings.

Table 5.6 Root length (mm) as affected by the temperature by cultivar interaction during planting two

Cultivar	Temperature (°C)				Average
	35	40	45	50	
AGSUN 8251	4.657	7.764	4.879	2.763	**5.016**
AGSUN 5264	5.773	9.538	5.546	2.939	**5.949**
AGSUN 5671	4.715	5.293	4.827	2.313	**4.287**
PAN 7033	3.607	7.616	4.678	3.037	**4.735**
PAN 7049	4.340	8.206	5.402	2.590	**5.135**
PAN 7050	4.773	8.986	4.164	1.828	**4.938**
PAN 7057	6.957	10.217	7.616	3.736	**7.132**
Average	**4.975**	**8.231**	**5.302**	**2.744**	
$LSD_{(T\leq 0.05)}$ C × T = 2.2					

5.3.2.2 Root length with surface crack

Root length of seedlings was significantly influenced by temperature during the first and second planting with surface crack (Figure 5.3). Root length was significantly longer at 35 and 40°C than at 45 and 50°C for both plantings. Recorded root length at 35°C was the longest at both plantings while the shortest was recorded for the first planting at 45°C and the second planting at 50°C (Figure 5.3).

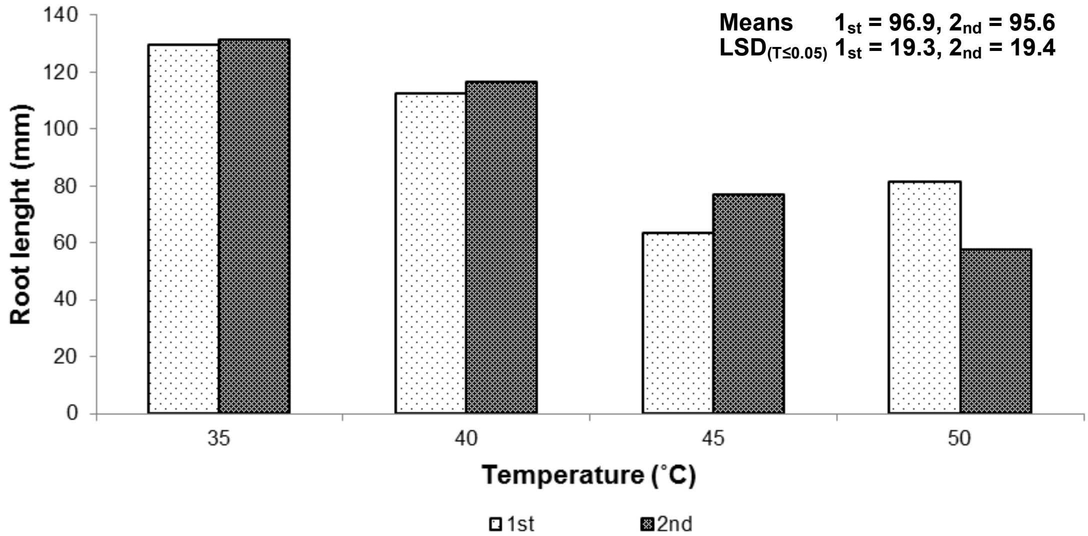


Figure 5.3 Root length with surface crack as affected by temperature treatment at both plantings.

5.3.2.3 Root length 48 hours after surface crack

Root length of seedlings 48 hours after surface crack was significantly influenced by temperature only during the first and second planting (Figure 5.4). Root length at 35 and 40°C was significantly longer than that at 45 and 50°C for the first planting. At the second planting root length of seedlings at 35°C was significantly longer than at 45 and 50°C (Figure 5.4). The root length measured at 40 and 45°C did not differ significantly, but was significantly longer than the root length of 50°C.

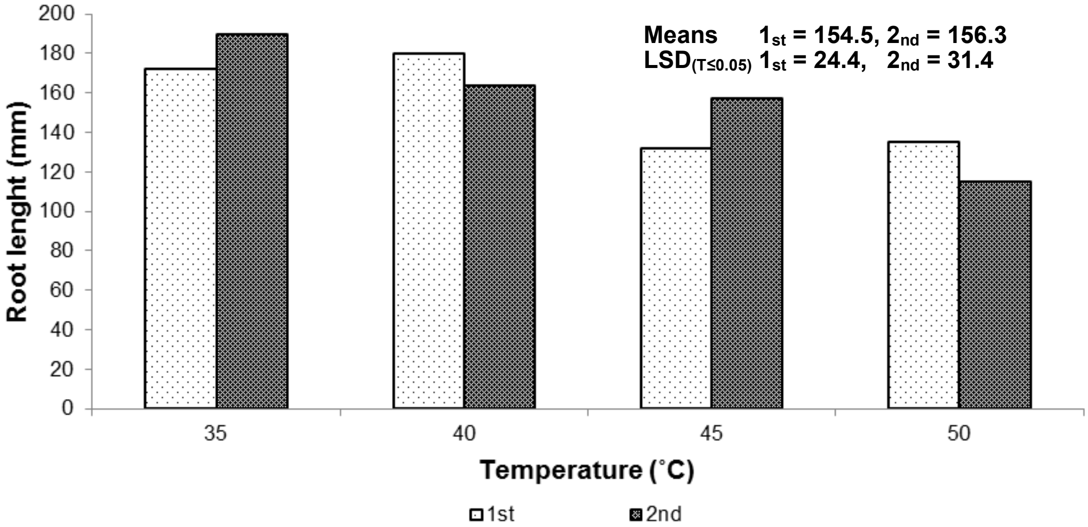


Figure 5.4 Root length 48 hours after surface crack as affected by temperature at both plantings.

5.3.3 Plant height

Plant height (measured with termination of the experiment) was significantly affected by temperature only for both plantings (Figure 5.5). Plant height was significantly greater at 35°C than at 45 and 50°C during the first planting. Plant height showed significant differences between all the temperature treatments during the second planting. Similar to the first planting plant height was the greatest at 35°C (Figure 5.5).

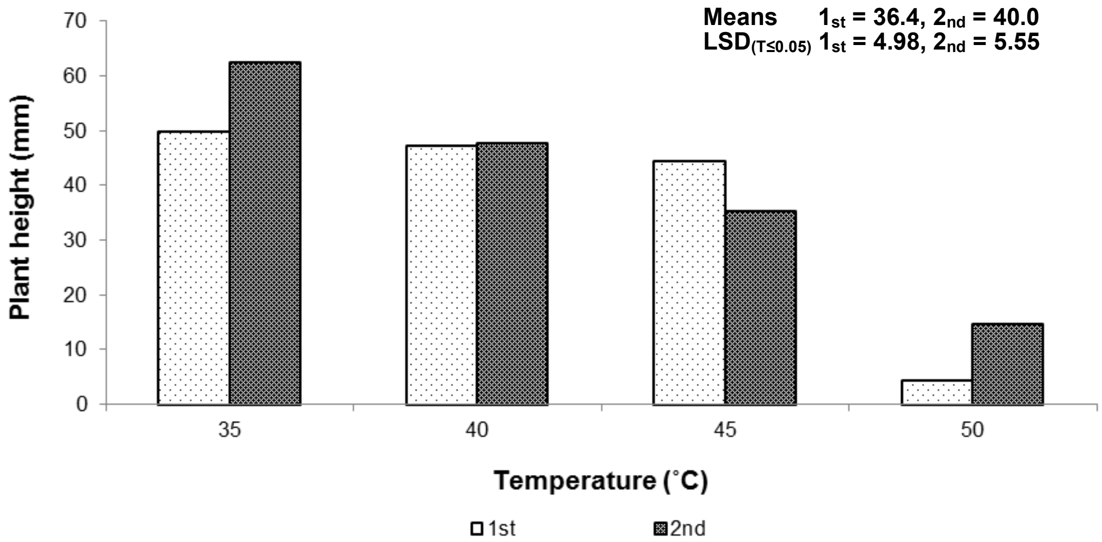


Figure 5.5 Plant height as affected by temperature at both plantings.

Plant height was significatly influenced by cultivar for both plantings (Figure 5.6). Plant height of PAN 7033 and PAN 7057 was significantly greater than AGSUN 8251 and AGSUN 5264 at both plantings. Plants of AGSUN 8251 was significantly smaller for both plantings compared to all cultivars. The tallest cultivar was PAN 7033 and PAN 7057 at the first and second planting, respectively (Figure 5.6).

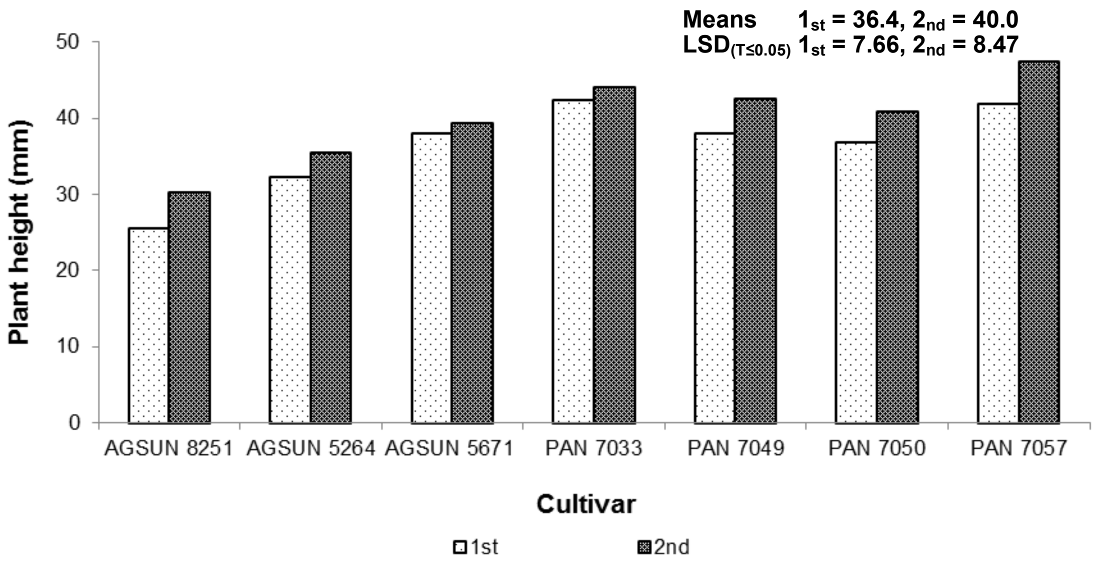


Figure 5.6 Plant height as affected by cultivar at both plantings.

5.3.4 Fresh mass

Fresh mass was significantly influenced by temperature only for both plantings (Figure 5.7). Significant differences were recorded for fresh mass during the first planting between all temperature treatments. At the second planting fresh mass of seedlings at 35 and 40°C was significantly greater than that recorded at 45 and 50°C. Plant fresh mass was also significantly greater at 45°C than at 50°C at the second planting (Figure 5.7).

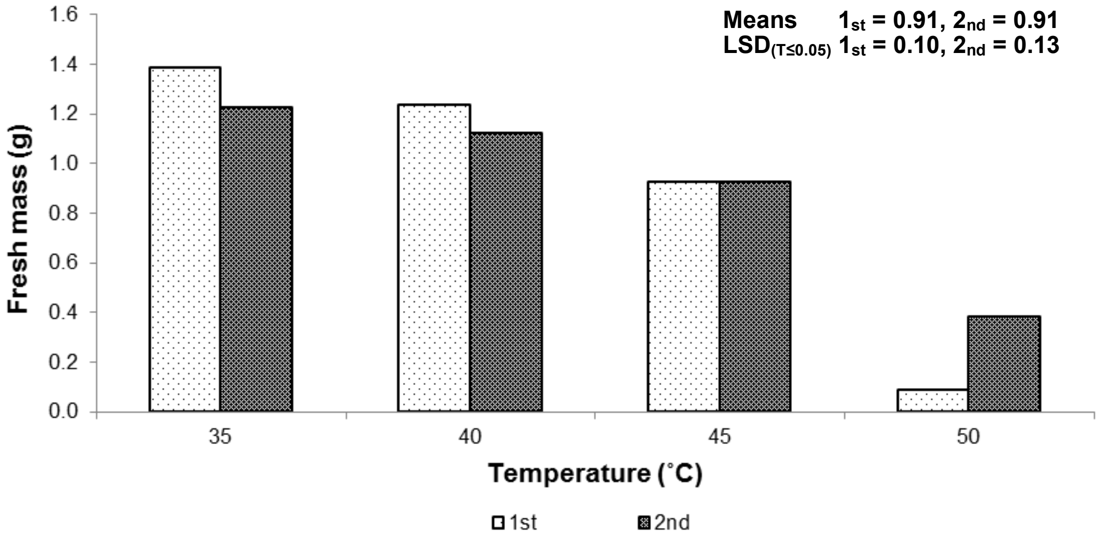


Figure 5.7 Fresh mass as affected by temperature at both plantings.

Cultivar significantly affected fresh mass for both plantings (Figure 5.8). The fresh mass of PAN 7033 and PAN 7057 were significantly greater than PAN 7049 and AGSUN 8251 during both plantings. AGSUN 8251 had the smallest recorded fresh mass for both plantings (Figure 5.8).

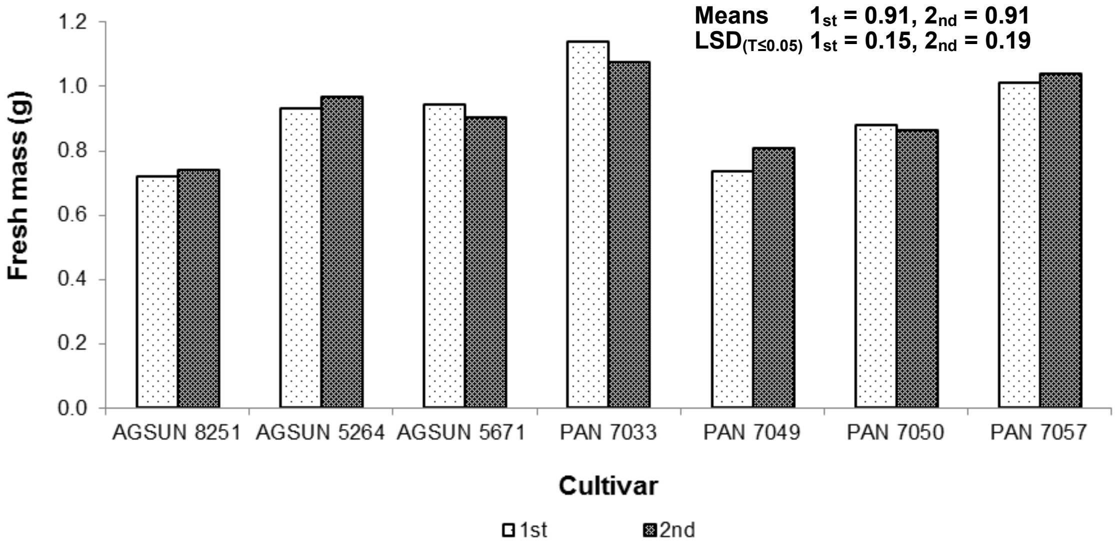


Figure 5.8 Fresh mass as affected by cultivar at both plantings.

5.3.5 Dry mass

Dry mass was significantly affected by temperature for both plantings (Figure 5.9). Dry mass showed significant differences between all temperature treatments during the first planting with a decrease as temperature increased. Dry mass at 35 and 40°C was significantly greater than at 45 and 50°C for the second planting. Seedling dry mass at 50°C was the smallest for both plantings (Figure 5.9).

Cultivar significantly affected dry mass for both plantings (Figure 5.10). The dry mass of both PAN 7033 and PAN 7057 was significantly greater than that of PAN 7049 and AGSUN 8251 at the first and AGSUN 8251 at the second planting (Figure 5.10). This tendency expectedly corresponds with the results of the fresh mass.

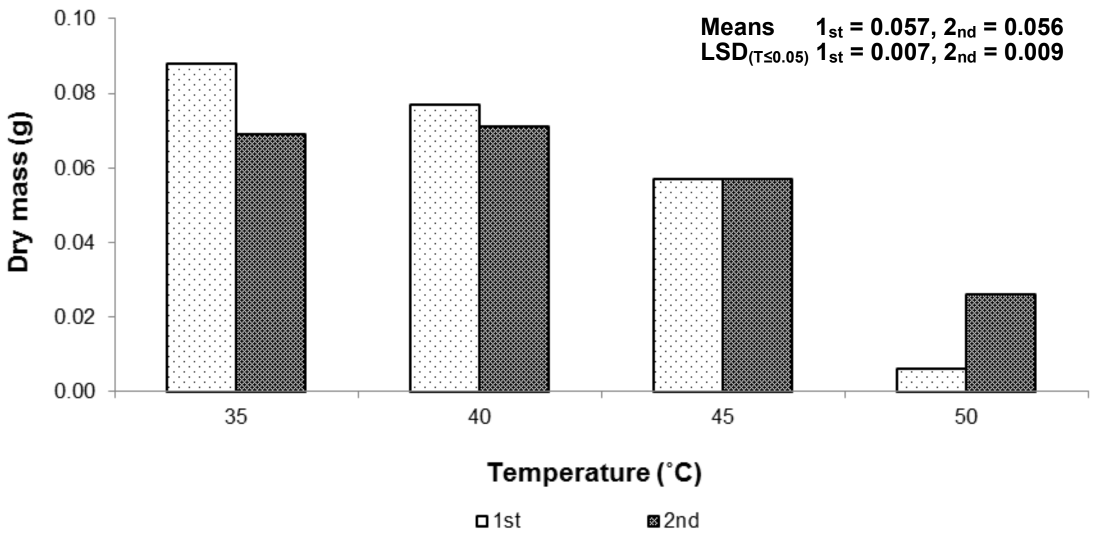


Figure 5.9 Dry mass as affected by temperature treatment at both plantings.

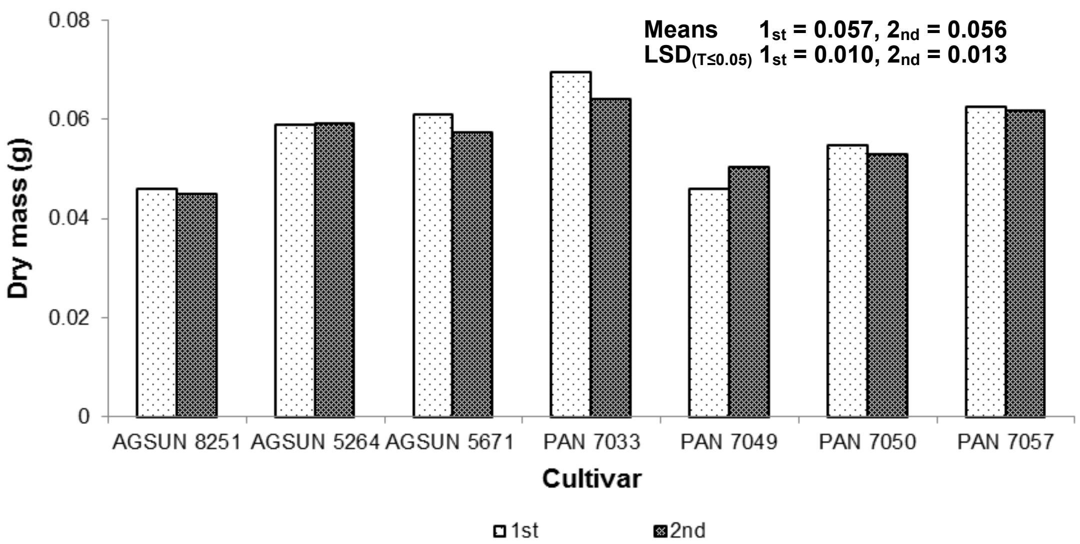


Figure 5.10 Dry mass as affected by cultivar treatment at both plantings.

5.3.6 Morphology

There were no definite visible differences between the different cultivars, but morphological variation was visible between temperature treatments. At 35 and 40°C emergence of seedlings was normal (Figure 5.11a) but at 45 and 50°C changes in morphology was evident (Figure 5.11b - f). Roots were affected during the first stages of root development, 24 hours after plant (Figure 5.11c), or after emergence was completed 48 hours after surface crack (d). Morphological variation was clearly visible for seedlings of one cultivar at a specific temperature (Figure 5.11e). This variation consisted of seeds showing signs of germination, followed by seedlings with poorly developed roots and finally seedlings with a nearly normal growth. Deformed seedlings were evident at 45 and 50°C temperatures (Figure 5.11f).

Figure 5.11 Morphology of seedlings when: (a) at normal emergence, (b) temperature damage below ground, (c & d) perished roots, (e) the same cultivar developed differently and (f) abnormal seedlings developed due to temperature stress.

5.4 Discussion

Soil temperature is an important environmental factor that can influence germination and emergence of sunflower seedlings. Although sunflowers are adapted to a wide range of temperatures (especially after emergence) the optimum soil temperature range for germination and emergence is estimated between 20-30°C (Corbineau *et al*., 1988; Gay *et al.,* 1991*;* Villabos *et al*., 1996; De Villiers, 2007).

Emergence commenced three days after plant at 35 and 40°C, four days after plant at 45°C, and five days after plant at 50°C (Chapter 6, Table 6.1). Average emergence index (EI) at 35 and 40°C was higher than at 45 and 50°C with the lowest EI at 50°C. Seedling vigour can decrease at temperatures above the optimum which may cause a lower emergence rate as was observed in this experiment (Anonymous, 1995; Nel, 2006). AGSUN 8251 and AGSUN 5264 had the highest EI while AGSUN 5671 had the lowest EI at both plantings. Although AGSUN 8251 had a faster emergence rate than the other cultivars the root growth, plant height, fresh and dry mass of this cultivar was consistently smaller for both plantings than the other cultivars.

Recorded root length 24 hours after plant was inconsistent when the two plantings were compared. The germination process is complete when the radicle (primary root) protrudes through the seed coat and elongate (Bewley and Black, 1994). Although planting was done at the same time, it can be assumed that the process of germination of all the seeds did not start at the same time. This may reflect on the root elongation within the first 24 hours.

Root length with surface crack and 48 hours after surface crack was consistently affected by temperature at both plantings. Roots were longer at 35 and 40°C than that at 45 and 50°C. This corresponds with previous research where root growth decreased when soil temperatures rose above the optimum of 23 - 25°C until it reach a lethal point at 45°C (Gay *et al*., 1991; McMichael & Quisenberry, 1993). Seiler (1998) reported that primary root length was the longest at 30°C at three, seven, and nine days after plant and started to decline at 35°C. However, this research showed that the root length was the longest at 35 and 40°C and declined at 45 and 50°C.

Above ground growth, such as plant height, fresh, and dry mass of PAN 7033 was consistently greater than the rest of the cultivars for both plantings. Plant height, fresh and dry mass was impaired by soil temperatures above 40°C. Although sunflowers are adapted to a wide range of temperature after emergence (Anonymous, 1995; De Villiers, 2010) these results indicate that high soil temperatures (>40°C) can delay emergence which in turn delays above ground growth rate.

Abnormal seedling growth was observed at soil temperatures above 40°C. This can indicate that thermal or secondary dormancy was induced which can cause seedlings to grow slowly or abnormally (Corbineau *et al*., 1988).

5.5 Conclusion

Temperature is an environmental variable that is vital for crop growth and development. Soil temperature is expected to be lower than the air temperature. Unfortunately, in the sandy soil of sub-Saharan Africa, temperature of the soil surface (0-20 mm) easily reaches temperatures in excess of 40°C. These temperatures damage seedlings during emergence if seeds are at a planting depth of 25 mm and cause uneven stand. Problems were experienced during this experiment (Chapter 6, Section 6.3) and the technique has room for improvement.

CHAPTER 6

WHY DIFFERENT EMERGENCE INDEX MODELS?

6.1 Introduction

Emergence is one of the most important stages (following germination) that influence crop establishment as well as crop success. Emergence represents the time in a crop cycle when the hypocotyl emerges through the soil surface and became visible above the ground (Forcella *et al*., 2000). Emergence is not only influenced by environmental and management conditions but seed dormancy and vigour may also have an effect. For these reasons emergence is considered by researchers as complicated (Alm *et al*., 1993; Forcella *et al*., 2000). This is further stressed by the difficulty to distinguish between germinating and emergence processes during seedling establishment. Ranal & De Santana (2006) make it clear that emergence rely on the germination process. Therefore, germination is as important as emergence under field conditions.

Predicting emergence has become very important over the years. Emergence index is a widely used method to determine the rate of emergence for weeds and annual crops and can therefore be used to better management practises. Several methods/models to determine the emergence index of seedlings were developed and used by researchers (Maguire, 1962; Mock & Eberhart, 1972; Fakorede & Ojo, 1981; Anfinrud & Schneiter, 1984; Scott *et al*., 1984; Nel, 1998b; Ahmad, 2001). These models all have the same function, but are diverse. It should be considered that each experiment or trial was done under different circumstances with different factors that could limit or delay emergence. For these reasons a comparison was done between some of the emergence index models to determine why the different models exist and why the model chosen was best when used in Chapters 3-5.

6.2 Different models

Three models will be discussed and compared in the following section as well as the model that was used in current experiments.

a) Fakorede & Ojo, (1981) from Mock & Eberhart, (1972)

$$\text{Emergence index (EI)} = \frac{\Sigma \text{ (Plants emerged in a day) (Days after planting)}}{\text{Plants emerged by nine days after planting}}$$

b) Anfinrud & Schneiter, (1984)

Emergence index (EI) = A(1/x) + …… + A(1/n)

Where: A = number of cotyledon pairs that emerged every day,

x = number of days after initial emergence,

n = last day emergence was counted

c) Nel, (1998a) modified from Anfinrud and Schneiter, (1984)

Emergence index (EI) = A3 + A4(0.9) + A5(0.8)

Where: A = percentage of hypocotyls that emerged every day (third to fifth day after planting ,

This EI discriminate against seedlings that emerge later than the initial emergence (day three).

d) Current experiments from Nel, (1998a)

Emergence index (EI) = A0 + Ax(0.95) + …. + An(0.7)

Where: A = number of cotyledons that emerged from soil,

x = day when emergence commenced,

n = day nine after emergence commenced

The discrimination factor was decreased to 5% because the model was determined over nine days and not three days as was the case for Nel, (1998a).

It should be noted terminology differs between models. At a) the original work was done on maize and number of plants was counted and not the number of cotyledons. The emergence percentage for each day was also not determined. At b) the number of cotyledons that emerged was counted. This implicates that the sunflower hypocotyl pulled the cotyledons through the soil surface to be visible above the ground. At c) the percentage of hypocotyls was counted. This indicates that the number of visible hypocotyls that were counted was expressed as a percentage. At d) the percentage of cotyledons was determined each day.

It is therefore important that the reader should acknowledge that emergence index can be used for different crops in different ways. It should also be noted that these approaches created diversity in models and outcome of results and should therefore be considered when interpreted.

6.3 Difficulties experienced during current experiments

The experiments that were executed from 2010 to 2013 had a number of difficulties and should be outlined before the models are compared. There were a number of variables that caused these difficulties in Chapters 3 and 4. These variables are as follow: two soils were used with two planting depths, planting was done at three planting dates, 18 cultivars were planted and three seed sizes of three cultivars were also tested. The biggest challenge was to plant when the weather (temperature and radiation) was at the optimum for the specific planting date. Planting was delayed when rain or cloudiness was expected for more than two to three consecutive days. The goal was to have ideal weather (no cloudiness that could cause reduced radiation) in the first five to ten days after planting. This would facilitate optimum soil temperatures for germination. Glasshouse temperatures were maintained at expected environmental temperatures.

In Chapter 5 the use of under floor heating cables, controlled by computer software, also caused difficulties, delays or replanting during the duration of the experiments. Any power failures during the experiment caused the soil to lose heat when least expected. Even with controlled soil temperatures radiation from the sun was important. The slightest change in weather between the replications of a temperature treatment could cause the emergence to vary. Emergence commenced at different days during all the experiments and treatments. This made the use of one specific model of emergence index difficult and complicated. It was therefore decided to standardise on the first day when emergence commenced between different treatments of an experiment. The number of days for emergence for the different treatments is indicated in Table 6.1.

Table 6.1 Indication of the first day of emergence for different treatments

Treatments	Days after planting									
Chapter 3 & 4	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
September 2010										
Bainsvlei 25mm						X				
Bainsvlei 50mm								X		
Tukulu 25mm						X				
Tukulu 50mm								X		
November 2010										
Bainsvlei 25mm					X					
Bainsvlei 50mm						X				
Tukulu 25mm					X					
Tukulu 50mm						X				
February 2011										
Bainsvlei 25mm				X						
Bainsvlei 50mm					X					
Tukulu 25mm				X						
Tukulu 50mm					X					
Chapter 5										
35 °C				X						
40 °C				X						
45 °C					X					
50 °C						X				

6.4 Model comparison

It is clear that different conclusions could be drawn from the comparison between models using a specific data set. Data was selected from research done in 2010 (Section 4.3.1.2, Table 4.2). The selected cultivars represent the cultivars that were above and below the average emergence index (EI) as well as cultivars of which the EI was intermediate (Table 6.2). According to the models of Fakorede & Ojo (1981) and Anfinrud & Schneiter (1984) a high count was equal to a high EI (faster emerging cultivars). However, there were inconsistencies when compared to the results of the current experiments (Table 6.2). It is important to consider that although the EI was calculated with the formula it was counted each day. From this perspective it was easier to spot cultivars that showed fast or slow emergence rates. The results from Fakorede & Ojo (1981) were inconclusive when compared to the rest of the models (Table 6.2). The difference between the results of the different models can be defined by the difference in the use of the models when EI was counted. The model of Fakorede & Ojo (1981) counted emergence five, seven and nine days after planting, while the rest of the models counted emergence for consecutive days, day three to seven.

The model of Anfinrud & Schneiter (1984) yielded the same results as the current experiments (Table 6.2). This could be due to the fact that the model of Anfinrud & Schneiter (1984) stretched over a longer period of time than the three days of Nel (1998a). Although there were differences between Nel (1998a), Anfinrud & Schneiter (1984) and the current experiments, it was only applicable to PAN 7049 and PAN 7057. The rest of the cultivars yielded the same results between previous mentioned models. Although Anfinrud & Schneiter (1984) did not specify the amount of days that emergence was counted or used for, it was assumed that 7 days after initial emergence commenced was sufficient. It was also stated from the study that plants was thinned during the V2 and V4 growth stages as described by Schneiter and Miller (1981). Emergence count should therefore have stopped when this procedure was performed. From these three models it is clear that AGSUN 8251 was the fastest cultivar to emerge while NK ARMONI was the slowest (Table 6.2).

Table 6.2 Comparison of emergence index models during September 2010 at 25mm planting depth in the Bainsvlei soil (numbers next to EI indicate highest to lowest EI)

Cultivars	**Fakorede & Ojo, (1981)**		**Anfinrud & Schneiter, (1984)**		**Nel, (1998)**		**Current experiments**	
AGSUN 8251	3.650	**3**	2.650	**1**	36.00	**1**	86.27	**1**
PAN 7033	3.150	**5**	2.510	**2**	20.00	**2**	84.58	**2**
PAN 7049	3.960	**2**	2.290	**4**	17.33	**3**	79.08	**4**
PAN 7057	4.440	**1**	2.430	**3**	1.330	**4**	81.49	**3**
NK ARMONI	3.450	**4**	1.540	**5**	0.000	**5**	54.25	**5**

Earlier work concentrated on germination rates/indexes which could confuse the reader as was done by Maguire (1962) and Scott *et al*., (1984). Ahmad (2001) defined an emergence index and emergence rate index which was based on Maguire (1962) and Scott *et al*., (1984). The model of Maguire (1962) was as follow:

$$\text{Germination rate} = \frac{\text{number of normal seedlings}}{\text{days to first count}} + \ldots\ldots\ldots + \frac{\text{number of normal seedlings}}{\text{days to final count}}$$

Scott *et al*., (1984) stated the follow:

$$\text{Germination (Sprouting) index (GI)} = \frac{\Sigma\, TiNi}{S}$$

Where: Ti = number of days after sprouting,

Ni = number of seeds germinated on day i,

S = total number of seeds planted

Although these models were based on germination it seems easy to be adopted as emergence index models.

Forcella *et al*. (2000) conclude that models should be improved to consider more variables such as the rate of dormancy induction, germination and seedling elongation. It was also concluded that current models use estimates of soil microclimate at single soil depths. Although it was made clear that there are studies which had better emergence models, none reached perfection (Forcella *et al*., 2000). This was also evident from this chapter.

6.4 Conclusion

The use of emergence index models is important for management practises during the production of sunflower. However, the confusion of terms, such as germination of seeds and emergence of seedlings, should be considered for future use. It is also important to acknowledge the fact that emergence is dependent on germination but does not determine the emergence rate. Although these models can be modified to determine germination or emergence index the objective of each experiment or trial should be considered. Limiting factors such as dormancy, germination rate, soil microclimate, and management practises should be considered when an emergence index is used. The selected model should work in the experiment and help reach the objective that was stipulated. It is therefore difficult to determine which models wanted work the best, universally.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Sunflower, *Helianathus annuus* L., is well adapted to a wide range of environmental conditions. This includes South Africa, which mainly produces oilseed sunflower of which the Free State province produces 50% and the North West 36%. These provinces are known for their sandy soils. Temperatures frequently rise above the critical level of 42°C in these sandy soils. High soil temperatures (>42°C) in combination with other factors, such as soil crusts, soil texture and planting techniques can influence seedling establishment. Seedling establishment is known as a critical phase that influences plant stand of sunflowers. This stage, known as the vegetative stage, includes seed germination, root development and elongation, elongation of hypocotyls, and, ultimately, the emergence of the seedling above the soil surface. It is mostly difficult to interpret data because agronomic experiments rarely distinguish between the sub phases. During this stage planting techniques and soil factors play a vital role and may influence seedling development, causing a delay in emergence.

Planting techniques (planting date and planting depth), soil factors (soil temperature and soil texture) and seed size may influence seedling establishment and emergence rate. Emergence of sunflower seedlings was prolonged when planted at 50 mm for both soil types (Bainsvlei and Tukulu) and at all planting dates. Slow emergence rates (at 50 mm) also affected above ground growth. Plant height and dry mass, with the exception of February 2011, was shorter and smaller at the 50 mm planting depth compared to 25 mm planting depth. During February 2011 the opposite was found for the Tukulu soil. Although 25 mm planting depth showed faster emergence rates, the question remain if it is viable when planted under dry land conditions in the field. Radiation on the soil surface is not always considered during planting of sunflower. This may cause soil temperature to rise ever faster during the warmer months of December and January on sandy soils with a clay content of ≤6%.

Ambient temperature during planting date plays a role in soil temperature. This in turn influences the emergence rates of seedlings. During September 2010 emergence was slow (5-7 days after plant) due to cool soil temperatures (±20°C), while faster emergence (3-4 days) was observed during February 2011 at higher soil temperatures

(±28-29°C). Although this was observed the above ground growth (plant height and dry mass) was taller and greater during November 2010 when soil temperatures was between 24 and 26°C. This can be explained by the following reasons: pathogens, such as *Alternaria* sp., *Fusarium* sp. and *Rhizopus oryzae* was observed during February 2011. These pathogens caused seedlings to rot and die. The Bainsvlei soil type also dried rapidly and a soil crust was formed causing damage to the seedlings which in turn was more susceptible to these pathogens. A higher rainfall and cloudiness was also experienced during February 2011. Although it was not tested, it can be assumed or speculated that due to cloudiness photosynthesis was probably reduced and therefore less carbohydrates was formed. This could explain the shorted plants and lower dry mass that was obtained at 25 mm planting depth during February 2011.

Smaller seeds emerged faster due to the small cavities in the hull. Seeds therefore absorb water faster from the soil, triggering imbibition which in turn triggers germination and the onset of emergence. Larger seeds contain a greater food reserve than smaller seeds and therefore develop seedlings with greater leaf area and dry mass.

Emergence of sunflower seedlings declined with soil temperatures increasing from 35 to 50°C (5°C increments). Seedling emergence, root length and above ground growth (plant height, fresh and dry mass) were impaired when soil temperatures reached 40°C and more. Seedling vigour was not tested and this may play a role at these high soil temperatures. Thermal or secondary dormancy should also be considered as a factor that may influence seedling vigour and therefore emergence. It is known that thermal dormancy can be induced when soil temperatures increase above the optimum for germination and seedling growth. This induction can cause seedlings to grow slowly and abnormally. Previous research was mostly done in a temperature range of 5 to 40°C which made the comparison of experiments with previous research difficult. The oil content of seeds as well as different seed lots was not included in the experiments. Literature states that higher oil content in the seeds could affect the emergence of seedlings. It is also possible that different seed lots of a cultivar can influence emergence rates of sunflower seedlings.

It was observed that a cultivar, eg. AGSUN 8251, could emerge faster than other cultivars, but had a lower or smaller growth rate above ground. A cultivar, such as PAN 7033 or PAN 7057, showed an average emergence rate when compared to a fast emerging cultivar, such as AGSUN 8251. However, PAN 7033 and PAN 7057, plant height, fresh or dry mass was greater than that of AGSUN 8251. Yield was not tested and it would therefore be reckless to speculate on the outcome. Fast or rapid emergence of cultivars can be favourable for seedling establishment. If the seedlings emerge slowly it is subjected to high soil temperatures in the top soil over a longer period of time Soil encrustation of the top soil can also delay emergence and with soil moisture losses drought stress may occur. Delayed emergence also exposes the germinating seed to pathogen infection. Although germination is tested and explained thoroughly in previous research and literature, it should be assumed that a high germination rate (> 85%) will not necessarily result in a high or even emergence rate. Is it therefore possible to consider the breeding of sunflower cultivars that are able to emerge faster and maintain a stable food reserve to complete the first phase of the vegetative growth stage namely germination and emergence?

The following recommendations can be considered when future research is done on emergence of sunflower seedlings.

- Yield of sunflowers should be considered after seedlings were exposed to high soil temperatures (35-50°C) during the germination to emergence phase. Photosynthesis rate can be tested after emergence when the first true leaves have unfolded to determine whether photosynthesis rate influences early growth of sunflowers;
- It is known that ethylene biosynthesis is a response which occurs in plants after it was exposed to stress. However production of ethylene can decline in plant organs when temperature increases above 37°C. Ethylene production can also temporarily be suppressed at these temperatures. Ethylene can break secondary or thermal dormancy in seeds which is responsible for the slow or abnormal growth of seedlings. Different cultivars are also able to develop different amounts of ethylene, therefore causing differences in emergence response between cultivars;
- Previous research also showed that soil crusts delayed sunflower emergence. In extreme cases this can cause the hypocotyl hook to snap. The strength of soil crusts and the effect it has on the hypocotyl hook should be tested. It was also observed that the hypocotyl hook thickened when it was exposed to prolonged soil crust conditions. These hypocotyl hooks can also be examined for possible hormones hormone changes;

- Oil content in seeds should be tested before the start of the experiment in the field to determine whether seeds with high oil content can have a better emergence rate than seeds with a low content of oils;
- In field conditions weeds should also be controlled. The effect of herbicides on seedlings after it was exposed to high soil temperatures (35-50°C) during emergence should also be tested;
- Seed lots of cultivars should be considered to determine whether there is a difference in emergence rates between seed lots of a cultivar as a result of different cultivation practises and/or environments; and
- Seedling vigour can be tested before and after exposure to high soil temperatures to determine whether it influence vigour and growth of seedlings.

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