RESPONSE OF ONION (*Allium cepa* L.) TO SOWING DATE AND PLANT POPULATION

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RESPONSE OF ONION (*Allium cepa* L.) TO SOWING DATE AND PLANT POPULATION

by

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DECLARATION

I declare that this dissertation is hereby submitted by me for the Magister Scientiae Agriculturae degree (Horticulture) at the University of the Free State. The work contained in this dissertation has not been previously submitted in any other educational institute. To my best of knowledge and belief, the dissertation contains no material previously published or written except where due reference is made. I furthermore concede copyright of the dissertation in favour of the University of the Free State.

Signature.......................... ......June 2012

Gagopale Bosekeng Date

DEDICATION

I dedicate this dissertation to my sons; Gagopale, Mothokhumo and Segolame who endured the absence of their father during their first months of life. To my loving wife, Chabo thank you for your patience of caring for the family in my absence and for encouragement that you gave me during my study. Your support is overwhelming.

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ABSTRACT

RESPONSE OF ONION (*Allium cepa* L.) CULTIVARS TO SOWING DATE AND PLANT POPULATION

Field trials were conducted on the West Campus facility of the Department of Soil, Crop and Climate Sciences of the University of the Free State in Bloemfontein during 2009 and 2010. The first trial during 2009 investigated the response of onion (*Allium cepa* L.) cultivars to sowing date. Cultivars namely; Charlize, Jaquar, Python and South Wester were used in 2009. Onions were sown on 31 April, 7 May and 21 May during 2009. The second trial was conducted during 2010, where cultivar Ceres Gold was used to replace South Wester as the latter was no-longer available in the market and sowing was done on 11 May, 25 May and 8 June. In both seasons, experiments were laid out as a randomized complete block design with each treatment combination replicated three times. During 2009, plant population of 41 plants m^{-2} was used, while in 2010 plant population of 61 plants m^{-2} was used. Plots of 1.8 m^2 were used with each plot having five rows. Each row had fifteen plants during 2009 and twenty two plants during 2010. Before planting, soil sampling and analysis were made, thereafter, fertilizers were applied as per soil analysis results.

A third field trial was conducted in 2010 to evaluate the three sowing dates (11 May, 25 May and 8 June) with a combination of five plant populations (95, 83, 74, 67 and 61 plants m^{-2}) using one onion cultivar ('Jaquar'). The experiment was laid out as a randomized complete bock design, with three replications having 1.8 m^2 plots. In each plot there were five rows. A bulb storage trial was also conducted under room (±25°C) and cold room temperatures (±5°C). This was done for all field trial in both seasons.

In a trial investigating response of cultivars to sowing date, better plant height, number of leaves, bulb fresh mass, and yield were observed when sowing was done from the end of April to the end of May. Sowing date significantly influenced bulb and neck diameters only during 2009. Bulbs were becoming more firm as sowing date was delayed, and the opposite was observed for bolting. Cultivar South Wester bolted more, followed by cultivar Jaquar while other cultivars did not bolt. The shape of bulbs was not significantly influenced by sowing date but it showed to be cultivar authentic. No split bulbs were observed.

In a trial of sowing date and plant population, significantly taller plants were obtained with early sowing date than the two later sowing dates. Leaf production was not significantly influenced by sowing date. Sowing date and plant population affected bulb fresh mass, yield, bulb and neck diameters as well as firmness. Sowing date did not influence bulb shape while plant population did. None of the bulbs bolted from this trial.

Mid-intermediate day cultivars ('South Wester' and 'Ceres Gold') recorded the shortest duration (105 days and 63 days respectively), while on average other cultivars were stored for 126 days in 2009 and 105 days in 2010. Storage disease (black mould), sprouting and loss of moisture from the bulbs were the contributing factors for reduction in storage duration. These factors were promoted by both field and storage conditions.

Onion producers should have adequate information on the cultivars and the production

CHAPTER 1

MOTIVATION AND OBJECTIVES

1.1 MOTIVATION

Onions (*Allium cepa* L.) belong to the family Alliaceae or Liliaceae. Other members belonging to the same family include shallot (*A. cepa* L. var. *aggregatum* G. Don.), common garlic (*A. sativum* L.), leek (*A. ampeloprasum* L. var. *porrum* L.) and chive (*A. schoenoprasum* L.) (Griffiths *et al.*, 2002). According to Hasegawa *et al.* (2001) onions originated from central Asia, and are cultivated in many countries around the world. In terms of income onions are the second most important vegetable crop after tomatoes in the world (Griffiths *et al.*, 2002; Mallor *et al.*, 2011). In South Africa, onions are considered to be the third most important vegetable crop after potatoes and tomatoes (Department of Agriculture, Forestry and Fisheries, 2010; The National Agricultural Directory, 2011). Onions sold on the twenty major fresh produce markets in South Africa earning an income of R 12.5 billion per annum (Department of Agriculture, Forestry and Fisheries, 2010).

The estimated area under onion production in South Africa varies between 6 500 and 7 000 ha. Of the 2 500 ha planted to intermediate day onion cultivars, the majority is planted in the Western Cape Province. Short day onion cultivars are planted on roughly 3 900 ha with the largest area north of the 28°S latitude (Hygrotech, 2010). Both short and intermediate day onion cultivars can be planted in the Free State Province. The sowing date in the Free State for short day onion cultivars ranges from March to April and for intermediate day cultivars from middle April to the end of May. These onions will be harvested from the end of October to December for short day cultivars and from December to February for the intermediate day cultivars (Joubert & Van Der Klashorst, 1997; Joubert & Van Niekerk, 1997).

The twenty major fresh produce markets are strategically situated all over the country and remain a critical important channel for marketing onions in South Africa. Approximately 471 708 tons of onions were produced during the 2008/09 season in South Africa, and during the 2009/10 season production was 3.6% higher (488 797 tons). However, sales of onion for the same period on the fresh produce markets increased with 1.3% from 293 740 to 297 459 tons (Department of Agriculture, Forestry and Fisheries, 2010). A total of 6 633.95 and 6 113.66 tons of onions were sold on the Mangaung Fresh Produce Market in Bloemfontein during 2008 and 2009, respectively (Department of Agriculture, Forestry and Fisheries, 2009).

The price of onions on the local fresh produce markets fluctuates from month to month and also from one year to the next. Market prices are mainly determined by supply and demand (Herregods, 2000). The fresh produce markets normally experience an over supply of onions from October to February and as a result, prices systematically decline during this period. For example, on the local fresh produce market of the Mangaung municipality in Bloemfontein during 2009, onions were sold at R 2 637.39 ton^{-1} in December and R 2 217.80 ton^{-1} in January where after it increased, peaking in May (R 5 016.58 ton^{-1}). During June and August of the same year, prices were still high ranging between R 4 790.52 ton^{-1} and R 3 659.27 ton^{-1} (Department of Agriculture, Forestry and Fisheries, 2009).

The export of onions from South Africa to neighboring African countries and beyond Africa increased by 73.5% from 15 410 tons in 2008/09 to 26 732 tons in 2009/10 (Department of Agriculture, Forestry and Fisheries, 2010). Table 1.1 show the quantities of onion South Africa exported in 2009 and higher quantities were exported to Mozambique (10 059 tons) (Department of Agriculture, Forestry and Fisheries, 2010).

Table 1.1: The quantity (tons) and percentages of onion exported from South Africa to various destinations in 2009 (Department of Agriculture, Forestry and Fisheries, 2010)

Importer	Share in South Africa's exports (%)	Exported quantity (ton)
Mozambique	40.90	10 059
Netherlands	16.80	4 975
Zimbabwe	13.00	2 904
Angola	5.20	909
France	4.00	578
Belgium	3.90	1 293
Mauritius	3.30	401
Ship Stores and bunkers	3.20	260
United Kingdom	2.90	1 043
Zambia	2.70	1 766
Congo	1.20	141
Brazil	0.80	1
Saint Helena	0.70	68
Ireland	0.60	200
Democratic Republic of Congo	0.50	134

Export of onions to Europe is relatively small (8 000 tons per annum) in comparison with other countries such as New Zealand, Australia and Argentina each exporting 160 000, 80 000 and 20 000 tons per annum, respectively (The National Agricultural Directory, 2007 & 2011). The export potential for onions to Europe is high provided that competitive cultivars are planted and strict quality control measures are taken into consideration (The

National Agricultural Directory, 2009). This therefore calls for research and developing of new high yielding onion cultivars that produce quality bulbs.

Onions are grown primarily for their use as food, adding flavours to food and taste as well as being used for processing such as pickling, freezing, dehydration, oil extraction. Young, healthy green leaves with their white bases are also eaten raw in salads. Randle & Bussard (1993) and Randle *et al.* (1998) emphasize the importance of cultivar choice when growing onions for consumption as cultivars differ in flavour. Onions are not grown only for consumption but are useful for medicinal purposes such as prevention and treatment of blood and heart diseases (Van der Meer, 1997; Cheema *et al.*, 2003). Onions are also a source of Vitamin C and E (Made *et al.,* 1994; Griffiths *et al.*, 2002; Tabor *et al.*, 2004; Block, 2005; El Assi & Abu-Rayyan, 2007). All these characteristics of onions have been found to contribute to the high demand for onions.

The increasing demand for onions both for consumption (El Assi & Abu-Rayyan, 2007; Biswas *et al.*, 2010) and medicinal purposes (Griffiths *et al.*, 2002; Block, 2005) increased the need for breeding new cultivars with a high yield and quality for a specific production area (Currah, 2002). High yielding onion cultivars and appropriate agronomic practices can help to meet the ever increasing demand for onions (Cheema *et al.*, 2003; Msuya *et al.*, 2005). Sowing date and plant population has a profound effect on the performance of onions. Sowing date is limited by the climate of a specific area that is determined by its geological location (latitude). The higher the latitude, the shorter the growing season and ultimately, it may be insufficient for onions to produce a larger leaf area and to bulb before the end of the growing season (Brewster, 2008). Early sown onions tend to have a longer growing season before bulb initiation resulting in larger plants and larger bulbs. However, large plants are more likely to reach the size at which they become sensitive to a cold stimulus causing bolting. Large plants are also associated with split bulbs. High onion yields are obtained when onions are sown early (Brewster, 1994) and when plant population ranged between 50 and 80 plants m^{-2} (Hatridge-Esh & Bennett, 1980).

For every new cultivar released there is a need to determine optimum sowing date and plant population for a specific onion production area. The objective of the current study was therefore to evaluate the performance of onion cultivars in view of their response to sowing date and plant population under the existing climatic conditions of Bloemfontein in the Central Free State, South Africa.

1.2 OBJECTIVES

1.2.1 Main objective

The main objective of the study was to determine the response of onions to sowing date and plant population.

1.2.1.1 Sub-objectives

- To determine the influence of sowing date on growth, yield and quality of different onion cultivars (Chapter 4).
- To determine the effect of plant population on the growth, yield and quality of the onion cv. Jaquar (Chapter 5).
- To determine the effect of sowing date and plant population on the bulb storage of different onion cultivars (Chapter 6).

REFERENCES

BISWAS, S.K., KHAIR, A., SARKER, P.K. & ALOM, M.S., 2010. Yield and storability of onion (*Allium cepa* L.) as affected by varying levels of irrigation. *Bangladesh J. Agric. Res.* 35, 247-255.

BLOCK, E., 2005. Biological activity of allium compounds: recent results. *Acta Hort.* 688, 41-57.

BREWSTER, J.L., 1994. Onions and other vegetable alliums. 1st edn., CAB International, Wallingford, United Kingdom.

BREWSTER, J.L., 2008. Onions and other vegetable alliums. 2nd edn., CAB International, Wallingford, United Kingdom.

CHEEMA, K.L., SAEED, A. & HABIB, M., 2003. Effect of sowing date on set size in various cultivars of onion (*Allium cepa* L.). *Int. J. Agric. Biol.* 5, 185-187.

CURRAH, L., 2002. Onions in the tropics: cultivars and country reports. *In:* H.D. Rabinowitch & L. Currah (eds.). Allium crop science: recent advances. CAB International, Wallingford, United Kingdom.

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES, 2009. Statistics on fresh produce markets. Department of Agriculture, Report 47, Pretoria, South Africa.

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES, 2010. A profile of the South African onion market value chain. Department of Agriculture, Pretoria. South Africa.

EL ASSI, N. & ABU-RAYYAN, A., 2007. Yield and quality of onion bulbs as affected by manure applications. *Acta Hort.* 741, 265-271.

GRIFFITHS, G., TRUEMAN, L., CROWTHER, T., THOMAS, B. & SMITH, B., 2002. Onions a global benefit to health. *Phytother. Res.* 16, 603-615.

HASEGAWA, A., YABUKI, H., NABEURA, T., FUKUI, H. & IWATA, T., 2001. Evaluation of bulb shape and fresh-weight of different onion cultivars. *Tech. Bull. Agric. Kagawa Univ.* 53, 71-77.

HATRIDGE-ESH, K.A. & BENNETT, J.P., 1980. Effects of seed weight, plant density and spacing on yield responses of onion. *J. Hort. Sci.* 55, 247-252.

HERREGODS, M., 2000. Postharvest market quality preferences for fruit and vegetables. *Acta Hort.* 518, 207-212.

HYGROTECH, 2010. Production guidelines of onions. Hygrotech Sustainable Solutions. Hygrotech, Pretoria, South Africa.

JOUBERT, T.G. LA G. & VAN DER KLASHORST, E., 1997. The marketing, grading and export of onions. Onions J.1. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

JOUBERT, T.G. LA. G. & VAN NIEKERK, A.C., 1997. General information and cultivation of onions. Onions A.2. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

MADE, J.M., WRIGHT, B.S. & MARAMBA, P., 1994. Onion production and constrains in Zimbabwe: with specific reference to the agricultural development authority (ADA). *Acta Hort.* 358, 349-351.

MALLOR, C., BALCELLS, M., MALLOR, F. & SALES, E., 2011. Genetic variation for bulb size, soluble solids content and pungency in the Spanish sweet onion variety Fuentes de Ebro. Response to selection for low pungency. *Plant Breed.* 130, 55-59.

MSUYA, D.G., REUBEN, S.O.W.M., MBILINYI, L.B., MAERERE, A.P., MSOGOYA, T., MULUNGU, L.S. & MISANGU, R.N., 2005. Evaluation of field performance and storage of some tropical short-day onion (*Allium cepa* L.) cultivars. *W. Afr. J. Ecol.* 8, 10-18.

RANDLE, W.M. & BUSSARD, M.L., 1993. Pungency and sugars of short day onions as affected by sulfur nutrition. *J. Amer. Soc. Hort. Sci.* 118, 766-770.

RANDLE, W.M., KOPSELL, D.A., KOPSELL, D.E., SNYDER, R.L. & TORRANCE, R., 1998. Field sampling short day onions for bulb pungency. *HortTech.* 3, 329-332.

TABOR, G., GETAHUN, D. & ZELLEKE, A., 2004. Influence of storage duration on field sprouting, maturity and yield of some garlic (*Allium sativum* L.) cultivars at Debre Zeit, Ethiopia. *J. Hortic. Sci. Biotechnol.* 79, 871-876.

THE NATIONAL AGRICULTURAL DIRECTORY, 2007. Field crops and horticulture. Vegetables. Department of Agriculture, Pretoria, South Africa.

THE NATIONAL AGRICULTURAL DIRECTORY, 2009. Field crops and horticulture. Vegetables. Department of Agriculture, Pretoria, South Africa.

THE NATIONAL AGRICULTURAL DIRECTORY, 2011. Field crops and horticulture. Vegetables. Department of Agriculture, Pretoria, South Africa.

VAN DER MEER, Q.P., 1997. Old and new crops within edible allium. *Acta Hort.* 433, 17-31.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Growth and development of onions are mainly affected by environmental factors such as photoperiod and temperature. The performance of an onion cultivar depends on the interaction between genotype and the environment (Jilani & Ghaffoor, 2003). This interaction mainly determines cultivar selection for a specific area. On the other hand, agronomic practices such as sowing date, fertilization, irrigation and plant population among others, also have an effect on the growth, yield and quality of onion bulbs (Brewster, 2008).

This literature review will focus on climatic requirements, plant structure and growth stages of the onion plant. The influence of sowing date and plant population on growth, yield and quality of onions will also be discussed.

2.2 CLIMATIC REQUIREMENTS

2.2.1 Temperature

Temperature controls the development and the performance of the onion plant in all its growth phases (Coolong & Randle, 2003; Abu-Rayyan & Abu-Irmaileh, 2004; Ansari, 2007). To obtain germination percentage of at least 70% a temperature between 7.5 and 30°C is needed (Abu-Rayyan *et al.*, 2012). The optimum temperature for germination is 24°C, with 2 and 35°C the minimum and maximum temperatures, respectively (Comrie, 1997). According to Shanmugasundaram & Kalb (2001), onion seedlings grow the best at temperatures between 20 and 25°C. For optimum vegetative growth a temperature of between 18 and 22°C is needed, however plants will still grow at temperatures as low as 10 and as high as 27°C (Comrie, 1997). From bulb initiation up to harvesting, higher temperatures of between 25 and 28°C are required. When low temperatures (8 and 13°C) occur at the time of bulb initiation, bolting will occur instead of bulbing (Comrie, 1997).

2.2.2 Photoperiod

Photoperiod (day length) refers to the daily duration (hours) of light a plant is exposed to (Denisen, 1979). Onions react to day length for bulb initiation and the leaves of the plant are the photoperiodic stimulus receptor (Okporie & Ekpe, 2008). As the photoperiodic stimulus is received, formation of bladed green leaves near the apical meristem ceases and only bladeless leaves are formed. The photoperiodic stimulus favours carbohydrate accumulation exported from the leaf blade to the leaf sheath (Mondal *et al.*, 1986b; Mettananda & Fordham, 1999), causing the sheaths of the leaves to thicken and enlarge. These thickend leaf sheaths will develop into a storage organ, the bulb. As the bulb matures, the outer (oldest) one to four leaf scales dry out and become protective skin (Brewster, 1994).

The day length requirement for bulb formation differs according to cultivar type, ranging between 12 and 16 hours (van den Berg *et al.*, 1997). Adaptation of onion cultivars to a certain production area is largely dependent on the day length of that area and the day length requirement of the specific cultivar (Wiles, 1989). Short day onion cultivars require a day length of 11-12 hours for bulb formation, and can be planted in the tropics (30°N and S from the equator) (Figure 2.1) (Wiles, 1989). The day length in this area remains close to 12 hours throughout the year.

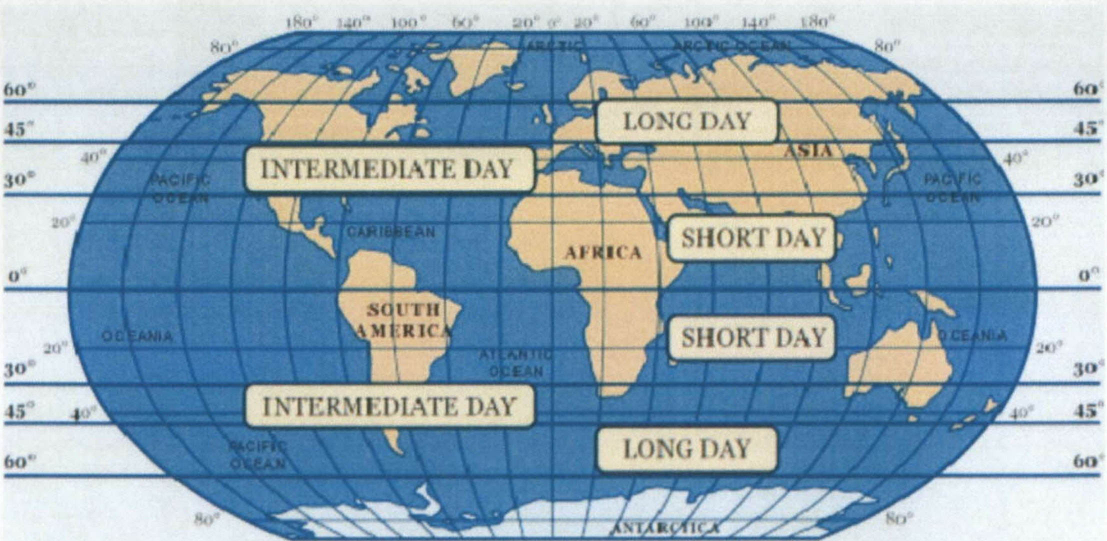

Figure 2.1: Adaption of onion cultivars to different latitudes (Hygrotech, 2010)

Intermediate day cultivars require a day length of 12-14 hours for bulbing and can be planted in areas between 30° and 45° latitude (Figure 2.1) as a winter or spring sown crop. Long day onion cultivars requiring a day length of 16 or more hours for bulbing are well adapted to areas between 45° to 60° latitude (Figure 2.1) (Hemy, 1984; van den Berg *et al.*, 1997). In South Africa, only intermediate day cultivars such as Jaquar and Python and short day cultivars such as Charlize can be planted. The reason for this being that the longest average day length in South Africa is only about 14.33 hours. Table 2.1 is a summary of different onion cultivars indicating their day length requirement and sowing dates for specific areas in South Africa.

Table 2.1: Summary of some onion cultivars classified according to their day length requirement for bulbing, cultivar type and sowing date for specific areas in South Africa (Comrie, 1997; Joubert & Van Niekerk, 1997; Messiaen & Rouamba, 2004; Hygrotech, 2009a & b)

Cultivar	Day length requirement (hours)	Type	Sowing date	Province
Charlize	< 12	Short	February-March	Limpopo & Northern
Pyramid	<12	Early-short	March-April	Gauteng
Hojem	<12	Late-short	March-April	Free State & Northern Cape
Python	12-14	Early-intermediate	May	Northern Cape
Ceres Gold	12-14	Mid-intermediate	Late May-June	Northern Cape
Australian Brown	12-14	Late-intermediate	May	Free State & Northern Cape
Caledon Globe	12-14	Late-intermediate	May	Free State & Northern Cape

If an onion cultivar is exposed to day length shorter than what is required, plants will continue to form leaves without forming bulbs (Wiles, 1994) and a high percentage bolting accompanied with thick bulb necks may also occur (González, 1997). Other studies showed that onion plants can revert to leaf production, even if bulb formation is far advanced, when plants are re-exposed to short photoperiods (Steer, 1980). On the other hand, a cultivar sown in areas where the photoperiod is longer than required, premature bulb formation is enhanced, bulb development and maturity rates increase, and this will result in smaller bulbs and low yields (Wickramasinghe *et al.*, 2000). Photoperiod of a specific production area at the time of bulb initiation will therefore influence cultivar selection.

2.2.3 Relative humidity

Under high atmospheric water vapour the rate of photosynthesis and water absorption by the plant roots is reduced because of the partial or complete closure of the stomata (Brewster, 2008). Warm, dry atmospheric conditions are important for bulb formation. Dry conditions reduce the occurrence of leaf diseases such as leaf blight (*Botrytis squamosa*) (Msuya *et al.*, 2005). Warm and dry conditions during harvesting promote the rapid drying of the leaves, causing the neck of the bulb to dry off quickly that will prevent moisture loss from the bulb and maintaining the firmness of the bulb.

2.3 PLANT STRUCTURE

The structure of the onion plant in the vegetative stage before bulb formation has been outlined by Jones & Mann (1963) and Brewster (2008) (Figure 2.2) as follows:

The stem is a flattened disc at the base of the plant and occur below the soil surface. At the center of the stem is the shoot apex from which all new leaves and roots are produced. Each leaf is made up of a blade and sheath. It is the leaf sheath that appear to be the stem of the plant above the soil level but is in fact a false or pseudo stem. As the leaf sheath develops, it surrounds the growing point and forms a tube enclosing the youngest developing leaves.

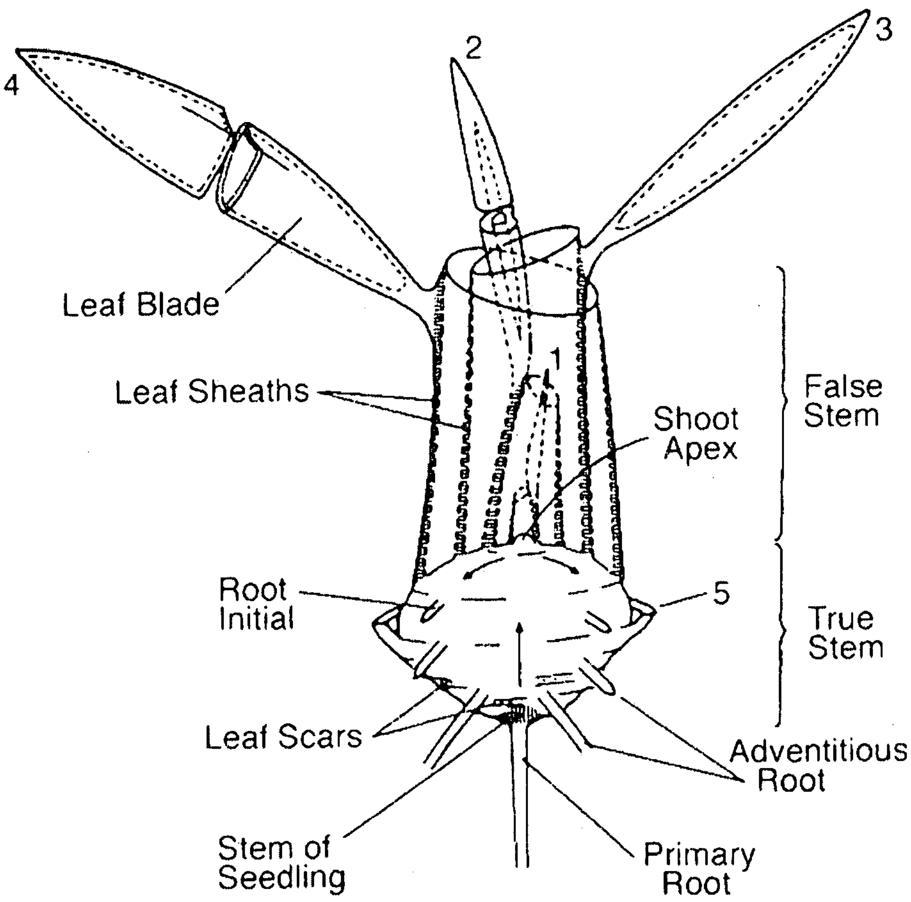

Figure 2.2: Plant structure of a young onion plant in the vegetative growth stage (Brewster, 1994)

Newly formed leaves can be seen at the junction of the leaf blade and sheath. As new leaves are formed and expand near the shoot apex, older sheath bases get pushed away from the apex. It is from the stem, near the base of young leaves where new roots form, except for the primary root that emerged from the seed. New roots always arise from the stem and the older ones get pushed further away from the shoot apex.

Onions have a tendency of producing lateral branches that can result in multiple growth points and split bulbs. These lateral branches can arise from the buds in the leaf axils. As soon as the photoperiod is long enough and the temperature is high enough bulb initiation will occur and the young developing leaves cease to form bladed leaves but only bladeless leaves will form. It is these swollen bladeless sheaths that form the onion bulb.

2.4 GROWTH STAGES

Compared to many other crops, onion has a fairly complex life cycle which can be divided into three main stages (Brewster, 1990 cited by Bosch Serra & Casanova, 2000). These developmental stages (Figure 2.3) are the seedling, vegetative and bulb stages (Bosch Serra & Casanova, 2000). According to Brewster (1994), during the first growth phase onion seed will start to germinate after sowing (Figure 2.3 A). During germination, the primary root will start to grow downwards (Figure 2.3 B), while the cotyledon pushes upwards through the soil surface as a loop or a hook and this stage is referred to as the loop stage. During the first leaf or flag stage (Figure 2.3 C), the first true leaf appears while the cotyledon is still sharply bent in a whip shape. The cotyledon starts to wither and falls following progressive desiccation during the cotyledon senescence stage (Figure 2.3 D) and the second and third true leaf appear. During the fourth leaf or leek stage, leaf four appears, the neck of the plant starts to thicken (Figure 2.3 E) and the first leaf starts to shrivel.

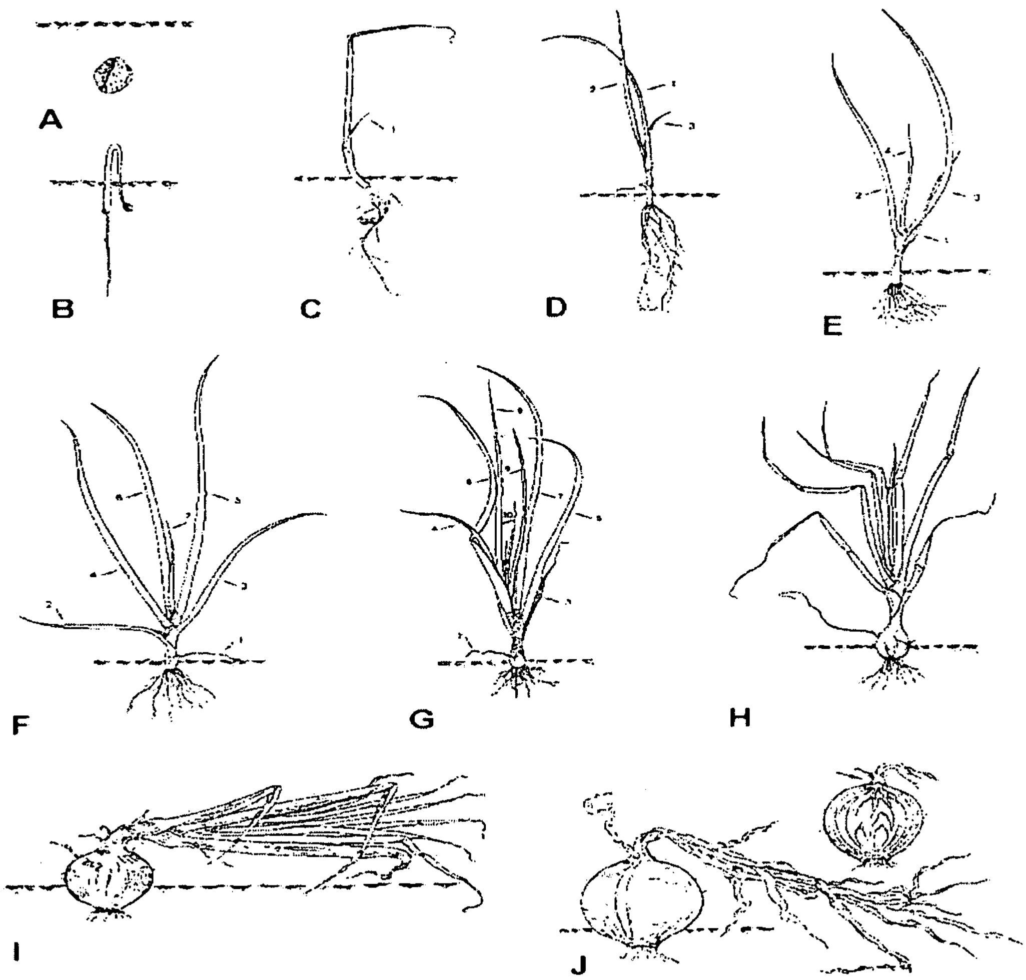

Figure 2.3: Different growth stages of the onion plant from seed up to bulb ripening (Brewster, 1994)

As the first leaf falls, the second leaf becomes detached at the sheath and starts to senescence from the tip, at the same time the fifth, sixth and seventh leaves appear. This stage is referred to as the fall of the first leaf stage (Figure 2.3 F). During the so-called bulbing stage (Figure 2.3 G) the bulb starts to form and the second and third leaf desiccate while leaves eight up to thirteen appear and the plant also reaches its maximum height.

As the onion bulb swells rapidly during the bulb swelling stage (Figure 2.3 H), the progressive desiccation of leaves four to six occur together with the tips of the younger leaves. Leaves start to bend or fold under their own weight. One or two more short leaf blades may still appear, while the dry outer bulb skin begins to form. During the fall-down or soft neck stage (Figure 2.3 I) the neck becomes hollow as new leaf blades cease to grow within it, and the neck tissues lose turgidity and soften, this leads to the foliage collapsing under its own weight and the bulb reaches its final size. During bulb ripening phase (Figure 2.3 J) the outer skin of the bulb dries out, cure and set while foliage senescense is complete and desiccation occurs.

2.5 EFFECT OF SOWING DATE

2.5.1 Growth and development

2.5.1.1 Germination and emergence

Onions are a cool season crop and tolerant to frost. Onion seed can germinate at temperatures as low as 1.4 to 3.5°C. However, for a germination and emergence percentage of more than 70%, temperatures between 7.5 and 30°C are needed (Abu-Rayyan *et al.*, 2012). In Germany, an emergence percentage of 90% and more was obtained with soil temperatures ranging between 10 to 25°C (Kretschmer, 1994). Ansari (2007) reported that a delayed sowing date accelerated the emergence of onion seedlings in Iran. Onion seedlings from seed sown in January emerge after 22 days experiencing an average temperature of 17.7°C, whereas seedlings of February sown seed emerge after only 10 days experiencing an average temperature of 24.7°C. Seedlings emerge after only 7 days when onion seed was sown in March when much higher average temperature (34.7°C) was experienced than for the earlier sowing dates. These results indicated that higher temperatures can shortened the number of days from germination to emergence. Onions therefore, can germinate at a wide temperature range with the highest germination percentage and seedling emergence between 15 to 25°C.

2.5.1.2 Seedling and vegetative growth

The seedling phase of onions (from the loop up to the cotyledon senescence stage, Figure 2.3 B-D), is a long and slow period of growth and can be as long as 2 to 3 months (Sullivan *et al.*, 2001; Brewster, 2008). The relative growth rate (RGR) of onion seedlings (1.00) is almost half of that of other cool season crops such as lettuce (1.91) and cabbage (1.96) and is temperature dependent. However, onion seedlings are the fastest growing of most edible alliums (Brewster, 2008).

Leaf growth and leaf canopy development during the vegetative growth phase (from the cotyledon senescence up to the fall of the first leaf stage (Figure 2.3 D-F) are temperature related. For leaf growth and leaf canopy development a minimum or base temperature of 6°C is required and at temperatures below 6°C leaf growth will cease. The relative leaf growth rate (RLGR) increase linearly with an increase in temperature from 6 to 20°C. With a further increase in temperature, growth rate will start to slow down and at temperatures above 26°C it will cease (Figure 2.4).

Relative leaf growth rate can be predicted by the equation:

$$\mathbf{RLGR = 0.0108\ (T - 6)}$$

RLGR = relative leaf growth rate per day

T = temperature (°C)

6 = base temperature (°C)

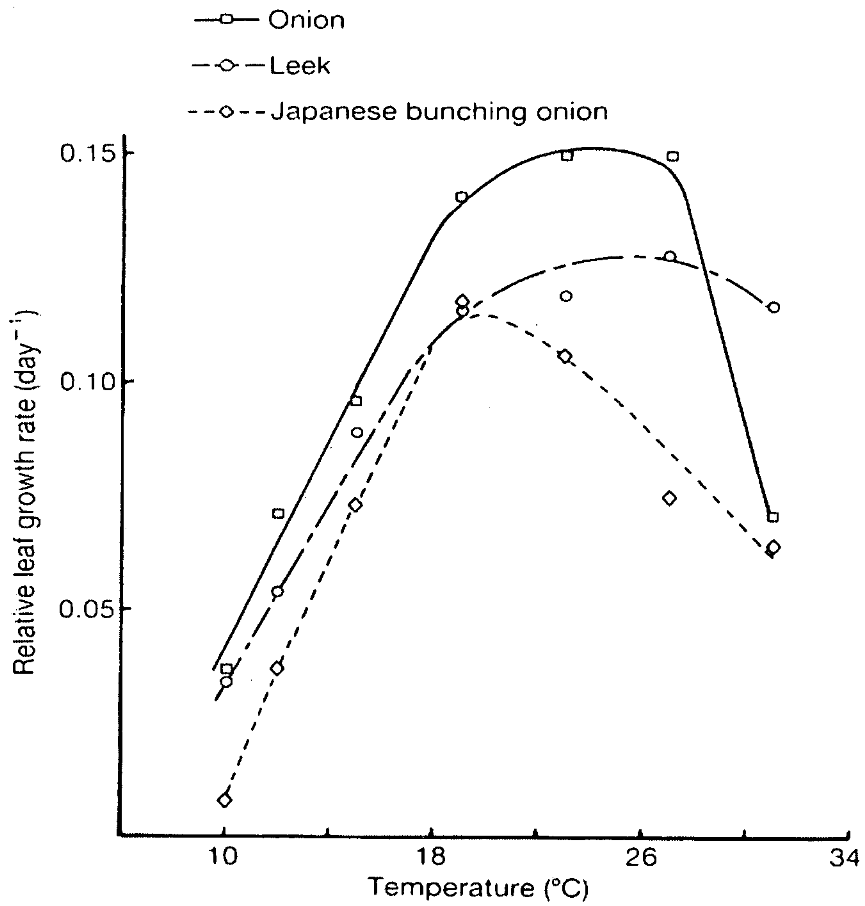

Figure 2.4: Relationships between relative leaf growth rate (RLGR) and temperature for onion showing high growth rate, leek and Japanese bunching onion seedlings growing under 12 h day lenghts (Brewster, 1994)

At the start of bulbing (Figure 2.3 G), the second and the third leaf desiccate while leaves eight to thirteen appear, and the plant reaches its maximum height. One or two more bladed leaves may still form before the soft neck stage (Figure 2.3 I) is reached (Brewster, 1994). Late sown onion plants tend to be small with the onset of bulbing, due to the short growth period allowed for the plant (Al-Moshileh, 2007). Bulb initiation for early and late sown onion plants of the same cultivar will occur at more or less the same time because the plant reacts mainly to daylight length for bulb initiation. The production of new leaves cease as soon as bulbing starts, implying that early sown plants will develop more, and larger leaves resulting in a larger leaf area compared to late sown plants (Brewster, 1994) (Table 2.2).

Table 2.2: The effect of sowing date on bulb yield, leaf area index (LAI) and light interception for onion cv. Augusta (Brewster, 1994)

Parameters	Sowing date	
	15 March	21 April
Bulb yield (kg m^{-2} of dry matter)	1.04	0.73
Leaf Area Index during bulbing	3.70	1.50
Percentage light interception by leaf canopy during bulbing	69.00	45.00

It is therefore, critical that plants acquire adequate leaf growth before the onset of bulbing (Mulungu *et al.*, 1998). This will result in a higher leaf area index for more light interception enabling the plant to photosynthesize more efficiently (Mondal *et al.*, 1986c; Sobeih & Wright, 1987). As leaf area index increases, bulb scale initiation and maturity are accelerated.

2.5.1.3 Bolting

Bolting is the development of a seed stalk, important for onion seed production but not bulb production (Voss *et al.*, 1999). Bolting will also reduce the marketable yield of onion bulbs. Un-timely bolting occurs when the onion plant is exposed to low temperatures (8-13°C) when plants are ready to start forming bulbs (Figure 2.3 F, start of bulbing phase). The sensitivity to low temperatures increases with an increase in plant age (Cramer, 2003). The number of leaves has been used to determine a critical plant size at which bolting will be induced under low temperature conditions. Khokhar *et al.* (2007) reported that the sensitive plant size is when 7 to 10 leaves have formed (at the end of the first leaf fall and the beginning of bulbing stage (Figure 2.3 F and G). When sowing is done too early in the season, the onion plant will reach the minimum plant size for bulbing when temperatures are still low and will bolt instead of forming bulbs. Sowing date therefore needs to be at a time to prevent plants receiving a cold spell when reaching a minimum plant size resulting in bolting instead of bulbing. However, with late sowing the occurrence of bolting is lower, but plants are still small when bulb formation starts resulting in small bulbs of a poor quality (Cramer, 2003). Therefore, cultivar selection and sowing date are important production factors that need to be taken in to consideration in preventing bolting to occur.

Agic *et al.* (2007) reported that bolting was enhanced by early sowing in the Republic of Macedonia. Late sown onions (1 September) had the lowest bolting percentage (13.12%) for all cultivars planted ('Sidra', 'Aldobo', 'Ranger' and 'Julio') compared to plants sown earlier on 10 and 25 August (34.81 and 27.00%) respectively. Temperatures ranged between 6.4 and 14.95°C when plants were at bulb initiation phase, and these temperatures are known to induce bolting instead of bulb initiation. Cultivars also differ in terms of bolting and in this study 'Aldobo' (7.02%) showed more resistance to bolting than 'Julio' (8.56%), 'Sidra' (23.69%) and 'Ranger' (60.64%). Al-Moshileh (2007) reported that early planted onions under central Saudi Arabian conditions resulted in a higher percentage of bolting than late plantings (Table 2.3).

Table 2.3: Effect of sowing date on bolting and yield of onions in Saudi Arabia (Al-Moshileh, 2007)

Planting date	Bolting (%)	Total yield (t ha^{-1})
15 August	14.3	22.5
1 September	26.3	26.3
15 September	8.7	27.7
1 October	3.5	23.1

It is evident that sowing date influenced bolting and that onion cultivars also differ regarding bolting tendency. Therefore, cultivar selection and planting date for a specific area are important production management aspects.

2.5.1.4 Bulb initiation

Bulb initiation of onions are the result of a combination of factors such as cultivar, temperature, light quality (red:far-red ratio), plant size (Mondal *et al.*, 1986c) and fertilizer (Sinclair, 1989). Onion bulb initiation commences as soon as the day length period is more than the minimum required by a specific cultivar (Quadir & Boulton, 2005). The leaves of the onion plant respond to day length and as soon as the required minimum length is reached the apical meristem no longer form bladed leaves but will now only form leaves with sheaths without blades (Brewster, 1997). The leaf sheaths will swell and form the bulb, contributing to the yield of onions (Quadir & Boulton, 2005). As stated earlier in Section 2.2.2, cultivars that need long days for bulb initiation will not form bulbs when sown in areas experiencing short days. This was supported by Bok *et al.* (2003) who reported that, although 'Australian Brown' an intermediate day cultivar (>14 hours) performs well in South Africa, it was not the case in Botswana, with the longest day length of only 13.40 hours.

As soon as the day length requirement is adequate, onion cultivars will form bulbs at more or less the same time even if they are sown on different dates. Given that the leaves receive the signals of solar radiation, sufficient leaf area index is therefore an important variable (Bull, 1968). Factors such as environmental conditions, nutrients, moisture (Hegde, 1986) and plant population influence the leaf area of a plant. The maximum projected leaf area per unit ground surface area is referred to as leaf area index (LAI) (Nock *et al.*, 2008). It is a determinant factor in radiation interception, photosynthesis, biomass accumulation, transpiration and energy transfer by the crop canopy (Akram-Ghaderi & Soltani, 2007). Leaf area index can be calculated using the following equation:

$$\text{Leaf area index} = \frac{\text{leaf area/plant}}{\text{land area/plant}}$$

Any factor decreasing the leaf area such as diseases, pests, hail, low plant population, sowing date, stress, insufficient nutrients or water during the growth period contribute to a lower yield of poor quality bulbs (Brewster, 1994). Therefore, to achieve a high yield of marketable onion bulbs, sowing should be done at an appropriate time to develop sufficient leaf area for interception of a high portion of incident light (Brewster, 1990).

A high percentage of radiation interception by onion plants due to an increase in plant population and earlier sowing advances bulb initiation (Mondal *et al.*, 1986a). The yield of late sown onion plants is reduced and might be attributed to a lower leaf area index and reduced leaf canopy light interception (Brewster, 1994). Leaf area index has an effect on the red:far-red (R:FR) ratio of light in the leaf canopy playing an important role in the rate of bulb development (Sobeih & Wright, 1987). Bulbing rate in a particular photoperiod depends on red:far-red ratio of light. Studies showed that bulb development accelerates as the red:far-red ratio decrease (Mondal *et al.*, 1986b). The red:far-red ratio decreases with an increased LAI accelerating bulb initiation (Mondal *et al.*, 1986c). Phytochromes (a pigment necessary for the response in photoperiodims) (Chen & Ni, 2006) absorbs much more red than far-red wavelengths, the red to far-red wavelength ratio decreases deeper into the leaf canopy. As a result, earlier bulb formation occurs as LAI increases. The maximum light absorption determines the rate of bulb development (De Visser, 1994) and under high LAI, maximum light is absorbed, resulting in earlier cessation of leaf production and advance bulbing.

Temperature also influences bulb formation. High temperatures between 25-27°C are favourable for bulbing and enhance earlier bulb initiation and maturity. Onions will start with bulb formation at a slightly shorter day length during warm weather conditions. Onion plants must accumulate thermal time (growing degree days above 5°C) from emergence of approximately 600 degree days (Lancaster *et al.*, 1996). Formation of bulbs will not commence if a minimum thermal time of 600 degree days is not met even if the critical photoperiod requirement is reached. However, plants may reach 600 degree days thermal time before the required day length is reached causing bulb initiation to start earlier. The calculation to determine thermal time (D) is:

$$D = \sum_{i=1}^{n} \left[\frac{(T_i^{max} + T_i^{min})}{2} - T_b \right]^{+}$$

where: D = thermal time

T^{max} and T^{min} = daily maximum and minimum temperature

T_b = base temperature

n = number of days between emergence and bulb initiation

Base temperature = 5°C

The plus sign indicates that the summation only included days when temperature exceeded the base temperature

From the literature reported above, it is clear that onions will only form bulbs if the day length and temperature requirements of the plant are met. Larger plants and warmer temperatures cause onion plants to start forming bulbs earlier. As bulbing is initiated when the day length exceeds a certain minimum number of hours, plants of the same onion cultivar tend to mature more or less at the same time in a particular area, regardless of sowing date. Early sown plants therefore, have a longer growth period resulting in larger plants and larger bulbs. However, marketable yield is not always high as early sown plants tend to produce larger plants that are prone to bolt or to form split bulbs that lower with the quality of the bulbs.

2.5.1.5 Bulb growth

The final bulb size depends on the physiological process regulating the development of bulbs and is also related to the thermal time accumulated before bulbing (Lancaster *et al.*, 1996). The number of leaves produced before bulbing is also regarded as key to the process of bulb growth since they are the main suppliers of assimilates for bulb expansion (Mettananda & Fordham, 1999; Valenzuela *et al.*, 1999). The time taken for leaves to develop and mature influences the leaf area and hence efficient photosynthetic capacity and potential for bulb growth (Lancaster *et al.*, 1996). Photosynthesis is the production of sucrose which will be transported and stored in the structural and storage tissue of the plant. During bulb development, soluble invertase converts sucrose to reducing sugars namely, glucose and fructose. This increase the osmotically active solutes in the outer sheath cells, and as water moves in, cell expansion takes place (Brewster, 2008). Therefore, if an onion cultivar is sown on a date which allows for long duration of vegetative growth, the better the growth of bulbs will be and ultimately better yield will be attained.

2.5.1.6 Bulb yield

Onion yield is affected by several factors including sowing date, plant population, light interception, soil fertility and cultivar. Enough vegetative growth before bulb initiation is important (Adjei-Twum, 1980 cited by Ibrahim, 2010) to obtain a high yield. When sowing is delayed, the plant completes the vegetative growth phase early and starts to bulb when it is still small, resulting in small bulbs and lower yields. The smaller leaf canopy of smaller plants intercept less light than larger plants resulting in lower yields compared to larger plants.

Cramer (2003) evaluated four onion cultivars (Daybreak, NuMex Mesa, NuMex Sweetpak and Texas Early White) during 1999 and 2000 in New Mexico. Onion seed was sown on 9, 23, and 30 September 1999 and on 8, 15, 22, and 29 September 2000. Bulb yield increased with a delayed sowing date from 9 September to 30 September for all the cultivars. Early sown plants (9 September) tend to bolt and it varied between 1.9 and 34.2% for the different cultivars, whereas for late sown (30 September) onions less bolting occurred in all the cultivars (0.3-1.7%).

Madisa (1994) reported that onions sown during mid-March in Botswana, yielded higher (43 t ha^{-1}) than those sown earlier in February (31 t ha^{-1}) and those sown later in April (23.6 t ha^{-1}). A high percentage of onion plants bolted (24%) in the February planting, while 7% of plants bolted with the March planting and no plants bolted in the April planting. The late planting (April) produced lower yields than the March planting due to a reduction in bulb size. Onion plants sown late (April) did not bolt because when low temperatures responsible for bolting prevailed, the plants were still small and had not yet reached minimum plant size.

In Nigeria, onion yield declined from 40 to less than 20 t ha^{-1} when the transplanting of seedlings was delayed from November to March in 2001/02. The same trend was observed during the 2002/03 season where the yield declined from 48 to less than 20 t ha^{-1} with a delayed transplanting date from December to March (Ibrahim, 2010). Lower yields caused by late transplanting forced plants to switch from leaf blade to bulb production while the leaf area index was still small and leaf canopy light interception was low compared to the earlier-sown plants.

The effect of sowing date (7 July, 21 July, 5 August, 20 August and 4 September) was evaluated on the yield of three onion cultivars ('Valencia', 'Valenciana-INIA' and 'Valcatorce') in Chile (González, 1997). The highest yield was obtained by 'Valcatorce' (26.30 t ha^{-1}), followed by 'Valenciana' (20.90 t ha^{-1}) and' then Valenciana-INIA' (16.67 t ha^{-1}). For the three onion cultivars, the best yield was obtained when sowing was done on 21 July (52.42 t ha^{-1}) and the lowest when sowing was done on 4 September (0.84 t ha^{-1}). Onion plants that were sown first (7 July) were subjected to low (<10°C) temperatures, causing the plants to bolt and small bulbs were harvested from this planting. Plants sown late (September) produced bulbs with thick necks and poor bulb initiation occured due to insufficient photoperiods.

Sowing date for a specific onion cultivar should be selected to ensure sufficient leaf growth before bulb initiation occurs to obtain high yields. However, a too long growth period before bulb initiation can also lead to bolting because this results in large plants exposed to low temperatures just before bulb initiation and split bulbs can also occur.

2.5.2 Bulb quality

A high bulb yield on its own does not guarantee the success of onion production, unless the quality of the bulbs (bulb diameter, neck diameter, firmness and bulb shape) meets the market demand.

2.5.2.1 Bulb and neck diameter

Bulb and neck diameter are important quality characteristics of onions. Consumers prefer medium size onions (40-69 mm) (Bosch Serra & Currah, 2002) that will attain higher prices on the market than the extra small (10-34 mm), small (35-39 mm), large (70-89 mm) and extra-large (>90 mm) bulbs. The average price per 10 kg bag is approximately R 16.00 for small, R 28.00 for medium and R 14.29 for large bulbs (M. Klashorst, personal communication)[1]

Bulbs with thin necks store longer than bulbs with thick necks (Gautam *et al.*, 2006). Thick bulb necks take longer to dry off after harvesting and provide a high risk for infection of post-harvest storage diseases such as bacterial soft rot (*Pseudomonas gladioli* pv. *alliicola* Burkholder) (Peters *et al.*, 1994; Wright & Grant, 1997).

Onion neck diameter increased significantly with a delayed sowing date from July to September in Chile (González, 1997). The experiment consisted of five sowing dates (7 July, 21 July, 5 August, 20 August and 5 September) and three cultivars (Valenciana, Valenciana-INIA and Valcatorce). Eighty one percent (81%) of the plants produced bulbs with thick necks when sown late (4 September) compared to 45.3% when sown early (7 July). Bulbing did not occur in the late sown (4 September) plants, due to a reduced leaf area index contributing to a delayed initiation of bulb scales (Brewster, 1990).

Ud-Deen (2008) planted onions on three different dates (30 October, 15 November and 30 November) in Bangladesh to examine the effect thereof on bulb growth (size) (Table 2.4). Larger bulbs (5.11 cm) were obtained with the earliest planting (30 October), followed by the bulbs of 15 November (4.81 cm) and then 30 November (4.50 cm) plantings. Small bulbs recorded for the late planting were due to lower temperatures and shorter day lengths.

The aim of any onion producer is to produce onions for a specific market. In producing for the fresh market, the aim should be to produce medium size bulbs to ensure a good price (Bosch Serra & Currah, 2002) with thin necks for possible long storage life (Mohanty & Prusti, 2001). However, there are also markets for other bulb sizes such as small and large in South Africa although the prices obtain for these classes are lower. The prices for

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[1] Mr M. Klashorst, 2011. Interaction market services Free State (Pty) Ltd t/a RSA market agents, P. O. Box 435, Bloemfontein, 9300

onions on the fresh produce market are mainly determined by supply and demand. When there is over supply on the market the price can drop to R 2 217.80 ton^{-1} and when onions are scarce prices can rise to R 5 016.58 ton^{-1} (Department of Agriculture, Forestry and Fisheries, 2009). Storage ability of an onion cultivar is therefore important for the producer so that he can store onions till there is a high demand and price is high for onions on the market (Joubert, 1997). Other than bulb size and good keeping quality, bulb shape is also essential. For example, in South Africa round bulbs are preferred (Eksteen *et al.*, 1997).

2.5.2.2 Bulb firmness

Bulb firmness is among the qualities that contribute to the consumer's perception of bulb quality. Bulb firmness has also been associated with the storability of onions (Mallor *et al.*, 2011). The physical and chemical composition of the cell walls influence bulb firmness. At harvest, dry matter content and total soluble solids (TSS), plays a role in bulb firmness. The differences in dry matter content, which may be due to differences in fructan concentration, could lead to an increase in cell water content and cell turgor which results in firmer plant tissue (Coolong *et al.*, 2008). Changes in the firmness during storage of bulbs are influenced by the activities of pectinases which control the composition of pectic polysaccharides. Pectin methylesterase (PME) is responsible for demethylesterfication of polygaacturonic acid chains. Once polygalacturonic acid is demethylestrified, they can bind to free calcium ions, resulting in increased bulb firmness. But, if polygalacturoneses (PG) are present, the galacturonic acid chains may be hydrolyzed, causing depolymerization of pectin and consequently softening of the bulbs.

Coolong *et al.* (2008) used refrigerated storage, 6.6±1.4°C and 82±4.2% relative humidity to evaluate the influence of firmness on bulb storage life of three onion cultivars (Pegasus, MSU 4535B and MBL 87-WOPL) in the USA. The short day cv. Pegasu recorded significantly softer bulbs (2.96 N) than the other two long day cv's. MSU 4535B and MBL87-WOPL (4.17 and 3.75 N, respectively). The difference in bulb firmness was attributed to the difference in dry matter content of the bulbs which was influenced by the fructan concentration in the cells, leading to an increase in cell water potential and cell turgor. 'MBL87-WOPL' had a higher dry matter content which ranged from 15 to 18% than 'Pegasus' (9 and 10.5%). After twelve weeks of storage, bulbs lost their firmness. Cultivar MSU 4535B lost its firmness by 14.93%, followed by cultivar Pegasus with 14.86% and MBL87-WOPL with 8.15%. The change in bulb firmness after 12 weeks of storage was attributed to water loss and change in bulb turgor. The authors also reported that the concentration of uronic acid in pectin had an influence on bulb firmness. Pectine accounts for about 30% of the polysaccharides in the primary cell wall and middle lamella (Coolong *et al.*, 2008). Cultivar MBL87-WOPL had the highest uronic acid concentration at harvest and the firmest bulbs, while cultivar Pegasus had the lowest uronic acid concentration and produced the softest bulbs. The differences in water soluble pectin uronic acid concentration at harvest might have led to differences in bulb scale firmness of different cultivars.

Firmness of onion bulbs is influenced by fertilizers such as sulphur (Lancaster *et al.*, 2001a) or copper (El-Tantawy & El-Beik, 2009). These fertilizers play a role in the accumulation of dry matter (Nasreen *et al.*, 2003) and strengthening bulb cells and in return increase onion bulb storability. Onions grown under low sulphur supplies produced softer bulbs than those grown with adequate sulphur (Lancaster *et al.*, 2001b). Irrigation and the size of the bulbs (Larsen *et al.*, 2009) also influence bulb firmness. Larger bulbs are less firm than smaller bulbs (Larsen *et al.*, 2009). The sizes of onion bulbs are dependent upon the size of the plants which can also be influenced by date of sowing (Cramer, 2003). Late sown plants produce small plants which yield too small bulbs (Brewster, 1994) that are firmer than larger bulbs (Larsen *et al.*, 2009).

Cramer & Corgan (2010) conducted an experiment in New Mexico during 2006/07, 2007/08 and 2008/09, to determine the firmness of two onion cultivars (NuMex Serenade and NuMex Starlite) sown on different dates. The different sowing dates in 2006/07 used were 13 September, 22 September, 25 September and 2 October. During 2007/08 three different sowing dates used were 14 September, 17 September and 20 September and during 2008/09 only one sowing date was used (30 September). Firmness was determined by squeezing bulbs by hand at two separate points at the vertical center and bulbs were rated on a scale of (1) soft to (9) hard. Their results showed that during 2006/07, harder bulbs were recorded from cultivar NuMex Serenade sown on 25 September (7.5) whereas, softer bulbs (5.7) were measured on cultivar 'NuMex Starlite' sown on 2 October. During 2007/08, hardest bulbs (7.5) were recorded on 'NuMex Serenade' sown on 14 September and the softest (6.3) recorded on 'NuMex Starlite' sown on 20 September. 'NuMex Serenade' was still harder (6.0) than 'NuMex Starlite' (4.4) during 2008/09 season. Result indicates that as sowing date is delayed, bulbs tend to be softer and that cultivars also differ in firmness. Firmness of onion bulbs is an important trait influencing the storage life of bulbs. Firmer bulbs can be stored for up to one month longer that softer bulbs (The National Agricultural Directory, 2009).

2.5.2.3 Bulb shape

The shape of onion bulbs is cultivar related and an important marketing characteristic. In South Africa and for export market, onion bulbs with a round shape are consumer's preference (Eksteen *et al.*, 1997; Bosch Serra & Currah, 2002). Bulb shape can be identified visually by comparing the shape of bulbs (Figure 2.5) with previous researcher's description and identification, or through the use of the bulb shape index.

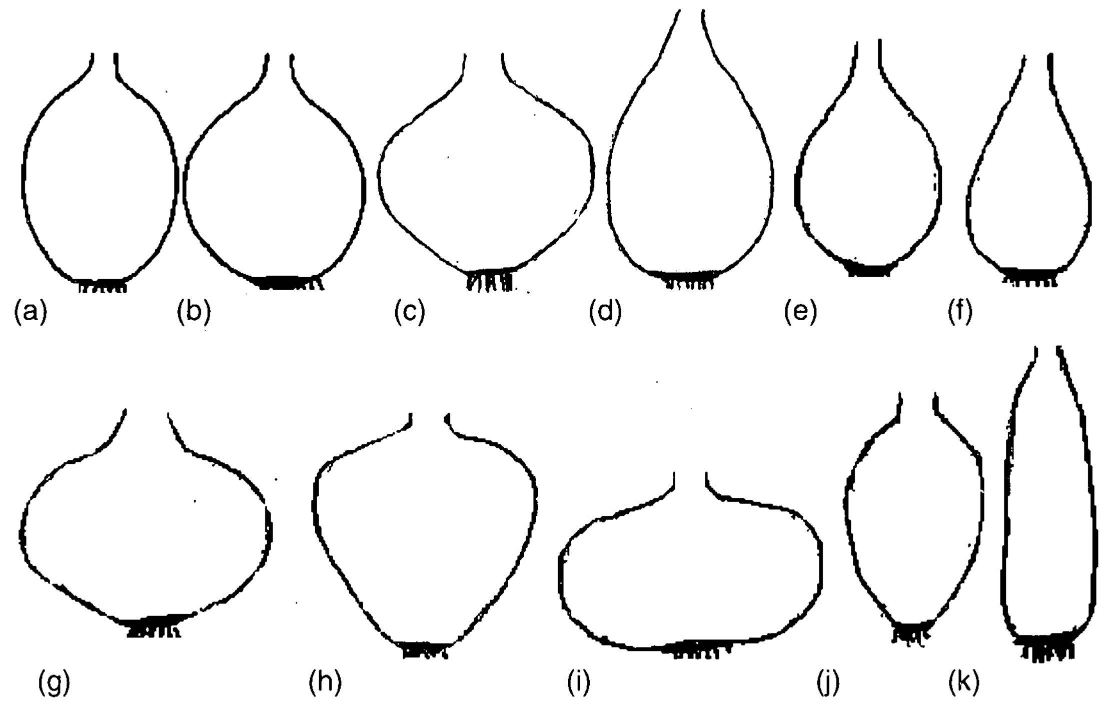


Figure 2.5: Different onion bulb shapes (a) deep round (Spanish) (b) round (c) rombic (d) broad egg shaped (globe) (e) egg shaped pointed (f) egg shaped (g) horizontal elliptic (h) road reversed (top shape) (i) flat (flat elliptic) (j) elliptic (k) cylindric (Van den Berg *et al.*, 1997)

The bulb shape index is described as the ratio of bulb height to diameter. Bulb height is measured from the base of the neck to the bottom of the bulb. The measurement of diameter is taken at the widest circumference of the bulb perpendicular to the neck and root axis (Grant & Carter, 1997; Hasegawa *et al.*, 2001). An onion bulb with a shape index of 1.1 ± 0.02 is classified as a globe bulb, while a bulb with a 1.8 ± 0.03 index as a flat bulb. Those with a 1.3 ± 0.05 index as a flatten shape and those with a 1.1 ± 0.02 index as nearly complete spherical bulb shape (Hasegawa *et al.*, 2001). Round bulbs have a shape index of 1.00 (Madalageri, 1993 cited by Mallikarjun, 2006).

Leilah *et al.* (2003) conducted an experiment in Egypt, evaluating the influence of planting date on the shape of onion bulbs using nine cultivars (El-Nobareia, El-Fayoum, El-

Gemmeiza, El-Mansoureia, Moshtor, Namol, New Nuclesus, Santrees and South El-Tahrir) and three transplanting dates (20 December, 10 January and 1 February) during 1996/97 and 1997/98. The author reported that a delayed transplanting date from 20 December to 1 February resulted in bulbs changing from flat towards a more rombic shape bulb, whereas the differences between early season transplanting (20 December) and mid season transplanting (10 January) were not significant. The change in bulb shape was attributed to an increase in neck size resulting from early bulbing in late transplanted plants. In both seasons, 'Nomal' and 'El-Gemmeiza' had the highest shape index of 0.91 and 0.92, respectively, and 'Moshtohor' recorded the lowest index of 0.82 which was due to the genetic variation between the cultivars.

2.6 INFLUENCE OF PLANT POPULATION

Selection of an optimum plant population is one of the critical production decision that onion producers must address before planting. Plant population refers to number of plants per square meter (plants m^{-2}) or hectare (plants ha^{-1}) and is important in onion production since it has an influence on growth, yield and quality of onion bulbs (Brewster, 1994).

Onion bulb size can be controlled to a certain extend by plant population. According to Brewster (1994) in order to produce large bulbs (>70 mm in diameter) a plant population of between 25 and 50 plants m^{-2} is required, for medium bulbs (25-50 mm) between 50 and 100 plants m^{-2} and for small bulbs (<50 mm) more than 100 plants m^{-2} are required.

2.6.1 Growth and development

2.6.1.1 Germination, emergence and seedling growth

Germination is primarily dependent upon temperature and soil moisture. No literature was found on the response of onion germination and emergence to plant population. However, seeding density can influence onion seedling growth. Mettananda & Fordham (1999) investigated the influence of four different sowing densities (10, 20, 30 and 40 g m^{-2}) on the growth of onion seedlings in the United Kingdom. Seeds were sown in trays and were kept in a glass house to produce seedlings for transplanting. Number of leaves produced by seedlings under the lower seeding densities (10 and 20 g m^{-2}) was significantly greater than under the higher densities (30 and 40 g m^{-2}). Leaf number increased from 3.7 at the high seeding density (40 g m^{-2}) to 5.1 at the lowest density (10 g m^{-2}). The same trend was observed for leaf area of the seedlings.

An experiment was conducted in the United Kingdom to observe the effect of plant population on onion seedling growth before transplanting (Weerasinghe & Fordham, 1994). The experiment consisted of two onion cultivars ('Hygro' and 'Hyfast') in multi celled modular seed trays providing for four plant populations. In each cell (3.7 cm^3) either 1, 2, 4 or 6 seedlings were planted. When transplanting, the transplants were planted in their clusters at a constant spacing of 10 x 10 cm to provide the original number of seedlings per module and final plant population were; 100, 200, 400 and 600 plants m^{-2}. The authors reported that the number of seedlings per cell had a significant influence on the growth of the seedlings at the time of transplanting. The number and size of leaves reduced significantly with an increasing number of plants per cell. More leaves (4.0) were recorded on plants that were single planted per cell and less (2.4) for plants that were planted at six seedlings per tray. They stated that an interplant competition during seedling growth reduced seedling size (leaf number).

2.6.1.2 Vegetative growth

Plant population has a major influence on plant growth and development of onions (Kanton *et al.*, 2002). The effect of plant population (56, 42 and 33 plants m^{-2}) on the growth of onion plants ('Red Nask') that was investigated in Pakistan did not have any effect on the number of leaves being produced by the plants (Khan *et al.*, 2002). Jilani (2004) also studied the effect of plant population on the number and length of onion leaves using plant populations of 20, 30 or 40 plants m^{-2} and five different cultivars (Naurang Local, Panyalla Local, Phulkara, Shah Alam Local and Swat-1) during two seasons (2000/01 and 2001/02) in Pakistan. The same trend was observed in the first season where number of leaves produced by the plants was not significantly influenced by plant population. In the second season, however, the number of leaves of plants planted at a population of 20 plants m^{-2} (12.05) was significantly more than the number of leaves per plant planted at 40 plants m^{-2} (9.99). Onion plants from the lowest plant population (20 plants m^{-2}) recorded the highest number of leaves (12.11) and the lowest number of leaves (10.97) were produced by plants planted at the highest plant population (40 plants m^{-2}) during 2000/01. The same trend was observed for leaf length where significantly longer leaves (37.99 cm) were recorded for plants planted at a plant population of 20 plants m^{-2} than 40 plants m^{-2} (33.43 cm) in 2001/02. This was attributed to increased competition for nutrients and water at the higher plant population.

In another experiment, also conducted in Pakistan by Farooq-Ch *et al.* (1990), using more or less the same plant populations (20, 30 and 40 plants m^{-2}), also showed that plant population had no significant effect on the number of leaves produced by onion plants. Plants from the lower populated (20 and 30 plant m^{-2}) plantings produced the most leaves (12.67 from both plant populations) compared to plants from the denser populated plantings of 40 plants m^{-2} (11.67).

The proportion of light intercepted by the leaf canopy of plants increased with an increase in plant population (Mondal *et al.*, 1986b). Brewster (1994) observed that as plant population increased from 25 to 400 plants m^{-2}, light interception increased. The highest percentage of light was intercepted by the leaf canopy (59.4%) of plants planted at 400 plants m^{-2} compared to 46.0% by plants planted at 100 plants m^{-2} and 30.0% of plants planted at 25 plants m^{-2}. The increased light interception under high plant populations is due to an increased LAI.

2.6.1.3 Bolting

In an experiment conducted by Brewster & Salter (1980) on the effect of plant population (43, 86, and 129 plants m^{-2}) and sowing date (2, 14 and 29 August in 1973, and 15 August in 1974) on two onion cultivars in United Kingdom, plant population did not significantly influence bolting. It was only sowing date and cultivars that significantly influenced bolting. Their results show that bolting can be minimized when sowing is delayed and by the use of cultivars which are not prone to bolting. In other studies (Bosch Serra & Domingo Olivé, 1999), results showed that with an increase in plant population, from 20 to 160 plants m^{-2}, the number of bolters increased. However, for bolting, a cold temperature spell (6 to 15°C) is needed and plants that are more sensitive are those that reached a minimum size of between 7 and 10 leaves (Khokhar *et al.*, 2007).

Bosch Serra & Domingo Olivé (1999) in Spain conducted two experiments, one under natural light condition and another one under black neutral shade, with the aim of investigating an influence of plant population (20, 40, 80 and 160 plants m^{-2}) on bolting using a long day cultivar (Valenciana de Grano). Under natural light condition, as plant population increased from 20 to 160 plants m^{-2}, number of bolters significantly increased from 8 to 75.

2.6.1.4 Bulb initiation, growth and maturity

Bulb initiation is dependent upon red:far red ratio within a crop canopy which modifies the crop's response to photoperiod (Sobeih & Wright, 1987). With an increasing plant population, leaf area index (LAI) increases, influencing light interception by the plant (Section 2.5.1.4) and accelerating bulb initiation (Mondal *et al.*, 1986c; Brewster, 2008).

According to McGeary (1985), an increase in plant population will result in the reduction in the duration of bulb maturity due to higher leaf area index (LAI). As LAI increases with plant population, percentage of light interception also increases (Mondal *et al.*, 1986a). Brewster (1994) studied three plant populations (25, 100 and 400 plants m^{-2}) and reported that the lowest plant population (25 plants m^{-2}) had the lowest LAI (0.82) followed by 100 plants m^{-2} (1.5) and then 400 plants m^{-2} (2.3). He further reported that plants under a high LAI (2.3) matured 10 days earlier than plants with LAI of 1.5 and 22 days earlier than plants with LAI of 0.82.

Rumpel & Felczyński (2000) reported that onions were harvested (50% neck fall stage) 10 days earlier at a plant population of 140 plant m^{-2} compared to onions planted at a population of 20 plants m^{-2}. Bulbs harvested from a plant population of 100 plants m^{-2} were harvested 12 days earlier than bulbs harvested from plants planted at 25 plants m^{-2} (Table 2.4) (Brewster, 2008). This is associated with a high leaf area index (LAI), that leads to a high percentage of light interception by the leaf canopy which will accelerate bulb maturity (Mondal *et al.*, 1986a). Optimum plant population is a key to attainment of good yields.

2.6.2 Yield (t ha^{-1})

Selection of plant population is an important management decision as onion yield can be influenced by plant population. It is critical to know the optimum plant population to achieve high yields of a good quality. However, the yield attained at a specific plant population is also influenced by growing conditions, in particular soil conditions and water availability.

Rumpel & Felczyński (2000) conducted a study to investigate the effect of plant populations (20, 40, 60, 80, 100 and 140 plants m^{-2}) on the yield of onions in Poland from 1991 to 1993 as well as during 1996. From trials conducted during 1991 to 1993, bulb yield increased from 20.5 to 32.8 t ha^{-1} as plant population increased from 20 to 80 plants m^{-2}. They reported a similar trend from the 1996 trial, where yield increased from 48.9 to 59.0 t ha^{-1} as plant population increased from 40 to 80 plants m^{-2}. During a relatively warm season (16.6°C) with inadequate soil moisture (160.2 mm), onion yields were lower than during a cool season (14±1°C) with adequate soil moisture (250-340 mm), which was the case for 1992, 1993 and 1996. As plant population increased, bulb yield also increased. Results of other studies however also showed an increase in yield when plant population increased from 60 to 100 plants m^{-2} but with a further increase in plant population yield started to decline (Dellacecca & Lovato, 2000; Kanton *et al.*, 2002).

2.6.3 Bulb quality

2.6.3.1 Bulb and neck diameter

The management of plant population is important as it influences bulb size and neck diameter. The bulb size and neck diameter play an important role in bulb quality. Farooq-Ch *et al.* (1990) studied the relationship between plant populations (20, 30 and 40 plants m^{-2}) and bulb diameter in Pakistan. They reported that bulb diameter decreased as plant population increased from 20 to 40 plants m^{-2}, although the difference was not significant. The reason for the reduction in bulb diameter as plant population increased was due to the fact that less populated plants utilized the larger space available for bulb formation.

An experiment was conducted in Peshawer during 2003, to study the influence of plant population (40, 60 and 80 plants m^{-2}) on the neck diameter of onions (Dawar *et al.*, 2005). The authors reported that as plant population increased from 40 to 80 plants m^{-2} onion neck diameter declined significantly from 20.9 to 18.3 mm. The thickest necks (20.9 mm) were produced by plants planted at a population of 40 plants m^{-2}, followed by the medium plant population of 60 plants m^{-2} (19.3 mm), while the thinnest necks (18.3 mm) were measured at the highest plant population (80 plants m^{-2}). Bulb necks become thinner as plant population increased because of the small plants attained at high plant population.

2.6.3.2 Split bulbs

Split bulbs is a result of lateral bud development. During the vegetative phase, lateral buds either remain dormant or they develop into multihearted bulbs which often double, i.e. divide into shoots. Eventually such plants produce more than one bulb (Chipman & Thorpe, 1977; Rabinowitch, 1979). This phenomenon is refered to as apical dominance (Tanaka *et al.*, 2006). If the axillary bud is not inhibited, it grows and produces a split bulb. This malformation can result from excessive soil moisture during bulb ripening or excessive nitrogen application during vegetative growth phase (Valenzuela *et al.*, 1999; Abdissa *et al.*, 2011), or temperature and day length (Steer, 1980). Splitting of bulbs also is found to be influenced by cultivar, with some cultivars being more susceptible to splitting (Steer, 1980; Jilani & Ghaffoor, 2003). Split bulbs are unmarketable (van den

Berg *et al.*, 1997). In an experiment that was conducted in Bangladesh by Khan *et al.* (2003), plants from a low plant population (48 plants m^{-2}) produced more split bulbs (24.34%) compared to those from a higher population of 162.8 plants m^{-2} (14.38%). Plants in lower plant population produced larger bulbs which were prone to splitting (Hassan & Ayoub, 1978; Rabinowitch, 1979).

2.6.3.3 Bulb shape

As was mentioned earlier in Section 2.5.3.3, one of the quality characteristics of onion bulbs influencing the market is bulb shape (Figure 2.5). Consumers prefer onions that are round in shape (Figure 2.5b) (Kimani *et al.*, 1993; Bosch Serra & Currah, 2002). An optimum plant population does not only address the issue of bulb size and yield, but also bulb shape (Grant & Carter, 1997). Apart from being a cultivar trait, bulb shape can be influenced by plant population. As plant population increased from 50 to 100 plants m^{-2} the percentage bulbs rejected on their shape increased from 7.9 to 15.3%. The same trend was observed when plant population increased from 65 to 130 plants m^{-2}, bulbs rejected also increased from 9.1 to 14.2% (Grant & Carter, 1997). An increase in plant population results in an elongated bulb with a shape index greater than 1.2 which is not considered as having desired shape by consumers (Eksteen *et al.*, 1997).

McGeary (1985) investigated the effect of plant population (178, 400, 625, 816, 1 111 and 1 600 plants m^{-2}) on bulb shape of pickled onions for the market in Australia. Onions for the pickled market should be small (25-45 mm) and round (Figure 2.5b). The results showed that as plant population increased, the number of irregular shaped bulbs also increased. The percentage of round bulbs declined by 13.3% as plant population increased from 178 to 1 600 plants m^{-2}.

2.7 STORAGE

The aim of onion bulb storage is to sustain quality and prolong the marketing period. Onions can be stored for up to seven months (Adamicki, 2005) provided the correct cultivar was selected, and bulbs were treated correctly during and after harvesting. Storage conditions play a major role in maintaining quality of onion bulbs (Adamicki, 2005).

Onion bulbs can be stored under different conditions such as non-refrigerated (field and room storage) and refrigerated storage. During field storage, onions are stacked in heaps, covered with straw or plastic sheet to protect the bulbs from sunburn or occasional rain

(Gubb & MacTavish, 2002). Onions can be stored in this manner for 1 to 3 weeks. Onion bulbs can also be stored by means of tying the leaves in bunches and hanging them on wires, either suspended from the roof beams or from poles of store rooms (Joubert, 1997). Care should be taken that they are not exposed to moisture (rain) and that the store room is dry and well ventilated (Joubert, 1997). In this way onions can be stored for a period of three months if they were well cured (Ko *et al.*, 2002). Onions can also be stored in cold rooms (refrigerated) for periods of up to six to seven months. The cold room temperature should be kept at 0.5°C and a relative humidity of 75%. Relative humidity higher or lower than 75% increase post-harvest diseases of onion bulbs in the cold room (Brice *et al.*, 1997 cited by Ramin (1999). Where it is not possible to maintain a relative humidity of 75%, an endeavour must be made to prevent it from bulding up further. This can be achieved by ventilation. Ventilation helps to keep the outer layer of onions dry and the bulbs dormant (Gubb & MacTavish, 2002).

Sprouting of bulbs will affect the shelf life of onions (Hurst *et al.*, 1985; Benkeblia *et al.*, 2002; Gautam *et al.*, 2006). After maturation of bulbs and neck fall, bulbs enter a state of dormancy, or rest period (Brewster, 1994). Sprouting is controlled by the amount of growth inhibitors (Grevsen & Sorensen, 2004) formed in the leaves. For example, the growth inhibitor allyl disulphide, is formed in the leaves and transported to the bulb before bulbs maturity (Hygrotech, 2010). Therefore, physiological maturity at harvesting influences the degree of sprouting during and after storage of onion bulbs. Brewster (1994) described physiological maturity as the degree of "top fall-down" or also called "leaf or neck fall". Onion bulbs store better if plants reached 50 to 90% physiological maturity before harvesting (Gubb & MacTavish, 2002). Harvesting too early (before 50% neck fall), results in insufficient growth inhibitor being translocated to the bulbs to prevent sprouting at an early stage of storage (Joubert, 1997). More matured bulbs will have high levels of allyl disulphide, resulting in an increased storing potential. Sprouting is also influenced by storage temperatures that range between 10 and 20°C (Benkeblia *et al.*, 2002). No sprouting occurred when bulbs were stored at 1°C (Brewster, 1987) or between 25 and 30°C (Miedema, 1994). Genetic composition (Miedema, 1994), time of harvesting (Grevsen & Sorensen, 2004) and application of nitrogen fertilizer close to harvesting (Sorensen & Grevsen, 2001; 2002) are also known to affect sprouting. Sprouted bulbs are of low quality and are not allowed in first class graded onions (Grevsen & Sorensen, 2004).

According to Gubb & MacTavish (2002), maleic hydrazide (MH) treatment can lengthen onion dormancy. It is a systemic plant regulator or inhibitor with some herbicidal activity whose mode of action is to inhibit cell division (Kubilius & Bushway, 1998). Maleic hydrazide inhibits mitosis in the meristematic region in order to prevent the development of sprouts and inhibiting bulb respiration (Benkeblia, 2004). The MH-treatment is done in the field as a pre-harvest treatment (El-Otmani *et al.*, 2003).

Cultivars differ in their storage ability because of their different genetic composition (Peters *et al.*, 1994; Sorensen & Grevsen, 2001; 2002). Short day cultivars can be stored for up to four months while intermediate day cultivars can be stored for up to 6-7 months (Hygrotech, 2009a & b). Therefore correct cultivar selection is essential for successful storage. Genetic factors such as dry matter content and dormancy influence bulb shelf life. Sugar metabolism is linked to onion bulb dormancy (Hurst *et al.*, 1985). Changes in the sugar content of bulbs is influenced by storage temperature, and sugar content increases as temperature increases (Benkeblia *et al.*, 2002). Hurst *et al.* (1985) reported that storing onion bulbs at 1°C resulted in onions becoming dormant after four weeks of storage since there was no change in the sugar content of the bulbs. However, when bulbs were stored at 4°C, the sugar content increased rapidly. This is attributed to hydrolytic activity of fructans in to carbohydrates (Benkeblia *et al.*, 2002).
Curing is a post harvest practice whereby the outer bulb skins, roots and neck tissue of harvested bulbs are allowed to dry. The outer skins of the bulbs serve as a protective barrier during handling and storage. According to Wright & Grant (1997), curing can be done in the field by 'wind rowing' or artificially with forced heated air. Curing is completed when the neck of the bulb dried out completely and is tightly closed (Gubb & MacTavish, 2002). This will lengthen the shelf life of bulbs and reduce infection of the bulbs by post-harvest pathogens (Wright & Grant, 1997).

Since bulb formation is influenced by day length, an onion cultivar sown on different dates will be harvested at approximately the same time. However, bulbs of onions sown earlier will have a better storage life (Galvan *et al.*, 1997). This is due to a longer growth period (Section 2.5.1.2) that will result in a larger leaf area, better photosynthesis and accumulation of assimilates and eventually result in larger bulbs that will store longer.

Moisture losses of bulbs caused by factors such as dehydration, rotting and sprouting, also limit storage life. The moisture loss of bulbs in storage is through the outer surface of the scales and the neck. Generally, the rate of moisture loss is lower in cultivars with a long storage life than in cultivars with a short storage life. The loss of moisture from bulbs may be prevented by maintaining relative humidity of between 65 to 75% in the storage atmosphere (Ramin, 1999).

Cultivar choice, physiological maturity, curing and storage conditions are all factors contributing to storage life of bulbs. Harvesting too early (before 50% neck fall), should be avoided since it results in insufficient translocation of growth inhibitors to the bulbs, causing early sprouting during storage.

2.8 CONCLUSIONS

Sowing date and plant population are among the critical factors determining the yield and quality of onions. Since bulbing in onions is enhanced as soon as photoperiod exceeds a certain critical minimum number of hours, a specific onion cultivar in one specific area will reach maturity at more or less the same time, regardless of sowing date. The earlier sown onions will have a longer growth period before bulb initiation, resulting in larger plants producing large bulbs. This, however, does not mean that the yield will be higher, because larger plants are inclined to produce a high percentage of unmarketable split bulbs. Larger plants are a result of early sowing and have a tendency to bolt when exposed to low temperatures. Therefore, the optimum sowing date for a specific area for a specific cultivar should be determined to avoid quality problems associated with either too early or too late sowing dates.

Another contributing factor to bulb size and yield is plant population (plants ha^{-1}). Plants that are highly populated tend to produce a high yield of small bulbs, whereas plants at a low population produce larger bulbs but with low yield. Densely populated plants mature earlier than not so dense populated plants. One optimum plant population can not be recommended because plant population is influenced by factors such as the market, the bulbs needed, climate, soil and cultivar. However, Brewster (1994) suggested that for medium bulbs (50-70 mm) a population of 50 to 100 plants m^{-2}, for large bulbs (>70 mm) 25-50 plants m^{-2} and for small bulbs (<50 mm) more than 100 plants m^{-2} is needed.

REFERENCES

ABDISSA, Y., TEKALIGN, T. & PANT, L.M., 2011. Growth, bulb yield and quality of onion (*Allium cepa* L.) as influenced by nitrogen and phosphorus fertilization on vertisol. I. Growth attributes, biomass production and bulb yield. *Afr. J. Agric. Res.* 6, 3252-3258.

ABU-RAYYAN, A., AKASH, M.W. & GIANQINTO, G., 2012. Onion seed germination as affected by temperature and light. *Int. J. Veg. Prod.* 10, 37-49.

ABU-RAYYAN, A.M. & ABU-IRMAILEH, B.E., 2004. Onion development and yield in response to manual cultivation, herbicides, or colored mulches. *J. Veg. Crop Prod.* 10, 37-49.

ADAMICKI, F., 2005. Effects of pre-harvest treatments and storage conditions on quality and shelf life of onions. *Acta Hort.* 688, 229-238.

AGIC, R., POPSIMONOVA, G., JANKULOVSKI, D. & MARTINOVSKI, G., 2007. Winter onion susceptibility to premature bolting depending on the variety and the sowing date. *Acta Hort.* 729, 271-276.

AKRAM-GHADERI, F. & SOLTANI, A., 2007. Leaf area relationship to plant vegetative characteristics in cotton (*Gossypium hirsutum* L.) grown in a temperate sub-humid environment. *Int. J. Plant Prod.* 1, 63-71.

AL-MOSHILEH, A.M., 2007. Effects of planting date and irrigation water level on onion (*Allium cepa* L.) production under central Saudi Arabian conditions. *Sci. J. King Faisal Univ.* 8, 75-85.

ANSARI, N.A., 2007. Effect of density, cultivars and sowing date on onion sets production. *Asian J. Plant Sci.* 6, 1147-1150.

BENKEBLIA, N., 2004. Effect of meleic hydrazide on respiratory parameters of stored onion bulbs (*Allium cepa* L.). *Braz. J. Plant Physiol.* 16, 47-52.

BENKEBLIA, N., VAROQUAUX, P., SHIOMI, N. & SAKAI, H., 2002. Storage technology of onion bulbs cv. Rouge Amposta: effects of irradiation, maleic hydrazide and carbamate isopropyl, N-phenyl (CIP) on respiration rate and carbohydrates. *Int. J. Food Sci. Tech.* 37, 169-175.

BOK, I., MADISA, M., MACHACHA, M., MOAMOGWE, M. & MORE, K., 2003. Manual for vegetable production in Botswana. Department of Agricultural Research, Gaborone, Botswana.

BOSCH SERRA, A.D. & CASANOVA, D., 2000. Estimation of onion (*Allium cepa* L.) biomass and light interception from reflectance measurements at field level. *Acta Hort.* 519, 53-63.

BOSCH SERRA, A.D. & CURRAH, L., 2002. Agronomy of onions. *In*: H.D. Rabinowitch & L. Currah (eds.). Allium crop science: recent advances. CAB International, Wallingford, United Kingdom.

BOSCH SERRA, A.D. & DOMINGO OLIVÉ, F., 1999. Ecophysiological aspects of nitrogen management in drip irrigated onion (*Allium cepa* L). *Acta Hort.* 506, 135-140.

BREWSTER, J.L., 1987. The effect of temperature on the rate of sprout growth and development within stored onion bulbs. *Ann. Appl. Biol.* 111, 463-467.

BREWSTER, J.L., 1990. The influence of cultural and environmental factors on the time of maturity of bulb onion crops. *Acta Hort.* 267, 289-296.

BREWSTER, J.L., 1994. Onions and other vegetable alliums. 1st edn., CAB International, Wallingford, United Kingdom.

BREWSTER, J.L., 1997. Onions and garlic. *In:* H.C. Wien (ed.). The physiology of vegetable crops. CAB International, Wallingford, United Kingdom.

BREWSTER, J.L., 2008. Onions and other vegetable alliums. 2nd edn., CAB International, Wallingford, United Kingdom.

BREWSTER, J.L. & SALTER, P.J., 1980. The effect of plant spacing on the yield and bolting of two cultivars of overwintered bulb onions. *J. Hort. Sci.* 55, 97-102.

BULL, T.A., 1968. Expansion of leaf area per plant in field bean (*Vicia fabia* L.) as related to daily maximum temperature. *J. Appl. Ecol.* 5, 61-68.

CHEN, M. & NI, M., 2006. Red and far-red insensitive 2, a ring domain zinc finger protein, mediates phytochrome controlled seedling deetiolation responses. *Plant Physiol.* 140, 457-465.

CHIPMAN, E.W. & THORPE, E., 1977. Effects of hilling and depth of plant setting on the incidence of multiple hearts and shape of sweet Spanish onion bulbs. *Can. J. Plant Sci.* 57, 1219-1221.

COMRIE, A.G., 1997. Climatic and soil requirements for onions. Onions B.1, Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

COOLONG, T.W. & RANDLE, W.M., 2003. Sulfur and nitrogen availability interact to affect the flavor biosynthetic pathway in onion. *J. Amer. Soc. Hort. Sci.* 128, 776-783.

COOLONG, T.W., RANDLE, W.M. & WICKER, L., 2008. Structural and chemical differences in the cell wall regions in relation to scale firmness of three onion (*Allium cepa* L.) selections at harvest and during storage. *J. Sci. Food Agric.* 88, 1277-1286.

CRAMER, C.S., 2003. Performance of fall-sown onion cultivars using four seeding dates. *J. Amer. Soc. Hort. Sci.* 128, 472-478.

CRAMER, C.S. & CORGAN, J.N., 2010. 'NuMex Serenade' onion. *HortScience* 45, 1889-1892.

DAWAR, N.M., WAZIR, F.K., DAWAR, M. & DAWAR, S.H., 2005. Effect of planting density on the performance of three varieties of onion under the agro-climatic conditions of Peshawar. *Sarhad J. Agric.* 21, 545-550.

DELLACECCA, V. & LOVATO, A.F.S., 2000. Effects of different plant densities and planting systems on onion (*Allium cepa* L.) bulb quality and yield. *Acta Hort.* 533, 197-203.

DENISEN, E.L., 1979. Principles of horticulture. 2nd ed., Macmillan Publishing Co., Inc, New York, United States of America.

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES, 2009. Statistics on fresh produce markets. Department of Agriculture, Report 47, Pretoria, South Africa.

DE VISSER, C.L.M., 1994. ALCEPAS, an onion growth model based on SUCROS87. I. Development of the model. *J. Hort. Sci.* 69, 501-518.

EKSTEEN, G.J., VAN DEN KLASHORST, E. & VAN ZIJI, B., 1997. Onions for export harvesting, handling and storage. Onions J.2. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

EL-OTMANI, M., NDIAYE, A., AIT-OUBAHOUA, A. & KAANANE, A., 2003. Effects of pre-harvest foliar application of maleic hydrazide and storage conditions on onion quality post-harvest. *Acta Hort.* 628, 615-622.

EL-TANTAWY, E.M. & EL-BEIK, K.A., 2009. Relationship between growth, yield and storability of onion (*Allium cepa* L.) with fertilization of nitrogen, sulphur and copper under calcareous soil conditions. *Res. J. Agric. Biol. Sci.* 5, 361-371.

FAROOQ-CH, M., MAHMOOD, K., KHAN, M.A. & QADIR, A., 1990. Effect of plant density on plant growth, size and yield of onion. *Pakistan J. Agric. Res.* 11, 239-242.

GALVAN, G., GONZALEZ IDIARTE, H. & SOLLIER, S., 1997. Productive adaptation of onion (*Allium cepa* L.) landraces used for postharvest storage. *Acta Hort.* 433, 165-170.

GAUTAM, I.P., KHATRI, B. & PAUDEL, G.P., 2006. Evaluation of different varieties of onion and their transplanting times for off-season production in mid hills of Nepal. *Nepal Agric. Res. J.* 7, 21-26.

GONZÁLEZ, M.I., 1997. Effect of sowing date on the production of three storage varieties of onion in the eight regions of Chile. *Acta Hort.* 433, 549-554.

GRANT, D.G. & CARTER, B.V., 1997. The influence of cultural factors on the bulb shape of the onion (*Allium cepa* L.) cultivar 'Pukekohe Longkeeper'. *Acta Hort.* 433, 527-532.

GREVSEN, K. & SORENSEN, J.N., 2004. Sprouting and yield in bulb onions (*Allium cepa* L.) as influenced by cultivar, plant establishment methods, maturity at harvest and storage conditions. *J. Hort. Sci. Biotechnol.* 79, 877-884.

GUBB, I.R. & MACTAVISH, H.S., 2002. Onion pre and postharvest considerations. *In*: H.D. Rabinowitch and L. Currah (eds.). Allium crop science: recent advances. CAB International, Wallingford, United Kingdom.

HASEGAWA, A., YABUKI, H., NABEURA, T., FUKUI, H. & IWATA, T., 2001. Evaluation of bulb shape and fresh-weight of different onion cultivars. *Tech. Bull. Agric. Kagawa Univ.* 53, 71-77.

HASSAN, M.S. & AYOUB, A.T., 1978. Effects of N, P and K on yield of onion in the Sudan Gezira. *Exp. Agric.* 14, 29-32.

HEGDE, D.M., 1986. Growth analysis of onion (*Allium cepa* L.) in relation to irrigation and nitrogen fertilization. *J. Agron. Crop Sci.* 157, 227-234.

HEMY, C., 1984. Growing vegetables in South Africa. Stigma Press, Pretoria, South Africa.

HURST, W.C., SHEWFELT, R.L. & SCHULER, G.A., 1985. Shelf life and quality changes in summer storage onions (*Allium cepa* L.). *J. Food Sci.* 50, 761-763.

HYGROTECH, 2009a. Onion variety profiles: Short day length. Hygrotech Sustainable Solutions. www.hygrotech.com (Accessed 10/05/09).

HYGROTECH, 2009b. Onion variety profiles: Intermediate day length. Hygrotech Sustainable Solutions. www.hygrotech.com (Accessed 10/05/09).

HYGROTECH, 2010. Production guidelines of onions. Hygrotech Sustainable Solutions. Hygrotech, Pretoria, South Africa.

IBRAHIM, N.D., 2010. Growth and yield of onion (*Allium cepa* L.) in Sokoto, Nigeria. *Agric. Biol. J. N. Am.* 1, 556-564.

JILANI, M.S., 2004. Studies on the management strategies for bulb and seed production of different cultivars of onion (*Allium cepa* L.). M.Sc. dissertation, North West Frotier Province of Pakistan. Agriculture University, Peshawar, Pakistan.

JILANI, M.S. & GHAFFOOR, A., 2003. Screening of local varieties of onion for bulb formation. *Int. J. Agric. Biol.* 5, 129-133.

JONES, H.A. & MANN, L.K., 1963. Onions and other allies. Interscience Publishers, Inc. New York, United States of America.

JOUBERT, T.G. LA G., 1997. Harvesting, handling and storage of onions. Onions I.1. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

JOUBERT, T.G. LA. G. & VAN NIEKERK, A.C., 1997. General information and cultivation of onions. Onions A.2. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

KANTON, A.L., ABBEY, L., HILLA, R.G., TABIL, M.A. & JAN, N.D., 2002. Density affects plant development and yield of bulb onion (*Allium cepa* L.) in Northern Ghana. *J. Veg. Crop Prod.* 8, 15-25.

KHAN, H., IQBAL, M., GHAFFOOR, A. & WASEEM, K., 2002. Effect of various plant spacing and different nitrogen levels on the growth and yield of onion (*Allium cepa* L.). *J. Biol. Sci.* 2, 545-547.

KHAN, M.A., HASAN, M.K., MIAH, M.A.J., ALAM, M.M. & MASUM, A.S.M.H., 2003. Effect of plant spacing on the growth and yield of different varieties of onion. *Pakistan J. Biol. Sci.* 6, 1582-1585.

KHOKHAR, K.M., HADLEY, P. & PEARSON, S., 2007. Effect of cold temperature durations of onion sets in store on the incidence of bolting, bulbing and seed yield. *Sci. Hortic.* 112, 16-22.

KIMANI, P.M., KARIUKI, J.W., PETERS, R. & RABINOWITCH, H.D., 1993. Influence of the environment on the performance of some onion cultivars in Kenya. *Afr. Crop Sci. J.* 1, 15-23.

KO, S.S., CHANG, W.N., WANG, J.F., CHERNG, S.J. & SHANMUGASUNDARAM, S., 2002. Storage variability among short day onion cultivars under high temperature and high relative humidity, and its relationship with disease incidence and bulb characteristics. *J. Amer. Soc. Hort. Sci.* 127, 848-854.

KRETSCHMER, M., 1994. Influence of temperature and soil water capacity on the emergence of onion seeds. *Acta Hort.* 362, 181-188.

KUBILIUS, D.T & BUSHWAY, R.J., 1998. Determination of maleic hydrazide in potatoes and onions by capillary electrophoresis. *J. Agric. Food Chem.* 46, 4224-4227.

LANCASTER, J.E., FARRANT, J. & SHAW, M.L., 2001a. Sulfur nutrition affects cellular sulfur, dry weight distribution, and bulb quality in onion. *J. Amer. Soc. Hort. Sci.* 126, 164-168.

LANCASTER, J.E., FARRANT, J. & SHAW, M., BYCROFT, B. & BRASH, D., 2001b. Does sulphur supply to the bulb affect storage of onions? *Acta Hort.* 555, 111-115.

LANCASTER, J.E., TRIGGS, C.M., DE RUITER, J.M. & GANDAR, P.W., 1996. Bulbing in onions: photoperiod and temperature requirements and prediction of bulb size and maturity. *Ann. Bot.* 78, 423-430.

LARSEN, T., SAXENA, A. & CRAMER, C.S., 2009. Relatedness of bulb firmness to other attributes of New Mexico onion entries. *Int. J. Veg. Sci.* 15, 206-217.

LEILAH, A.A., EL-KALLA, S.A., MOSTAFA, A.K. & AFIFI, H.M.A., 2003. Performance of some local Egyptian onion strains under different planting dates. *Sci. J. King Faisal Univ.* 4, 119-136.

MADISA, M.E., 1994. The effect of planting date, set size and spacing on the yield of onion (*Allium cepa* L.) in Botswana. *Acta Hort.* 358, 353-357.

MALLIKARJUN, N., 2006. Heterosis and combining ability studies in onion (*Allium cepa* L.). M.Sc. thesis, University of Agricultural Sciences, Dharwad, India. http://www.google.co.za (accessed on 03/02/12).

MALLOR, C., BALCELLS, M., MALLOR, F. & SALES, E., 2011. Genetic variation for bulb size, soluble solids content and pungency in the Spanish sweet onion variety Fuentes de Ebro. Response to selection for low pungency. *Plant Breed.* 103, 55-59.

McGEARY, D.J., 1985. The effects of plant density on the shape, size, uniformity, soluble solids content and yield of onions suitable for pickling. *J. Hort. Sci.* 60, 83-87.

MESSIAEN, C.M. & ROUAMBA, A., 2004. *Allium cepa* L. *In:* G.J.H. Grubben & O.A. Denton (eds.). Plant resources of tropical Africa 2: Vegetables. PROTA Foundations, Wagenigen, Netherland. www.books.google.co.za (accessed on 01/02/12).

METTANANDA, K.A. & FORDHAM, R., 1999. The effects of plant size and leaf number on the bulbing of tropical short-day onion cultivars (*Allium cepa* L.) under controlled environments in the United Kingdom and tropical field conditions in Sri Lanka. *J. Hort. Sci. Biotechnol.* 74, 622-631.

MIEDEMA, P., 1994. Bulb dormancy in onion. I. The effects of temperature and cultivar on sprouting and rooting. *J. Hort. Sci.* 69, 29-39.

MOHANTY, B.K & PRUSTI, A.M., 2001. Performance of common onion varieties in Kharif seasons. *J. Trop. Agric.* 39, 21-23.

MONDAL, M.F., BREWSTER, J.L., MORRIS, G.E.L. & BUTLER, H.A., 1986a. Bulb development in onion (*Allium cepa* L.). I. Effects of plant density and sowing date in field conditions. *Ann. Bot.* 58, 187-195.

MONDAL, M.F., BREWSTER, J.L., MORRIS, G.E.L. & BUTLER, H.A., 1986b. Bulb development in onion (*Allium cepa* L.). II. The influence of red: far-red spectral ratio and of photon flux density. *Ann. Bot.* 58, 197-206.

MONDAL, M.F., BREWSTER, J.L., MORRIS, G.E.L. & BUTLER, H.A., 1986c. Bulb development in onion (*Allium cepa* L.). III. Effects of the size of adjacent plants, shading by neutral and leaf filters, irrigation and nitrogen regime and the relationship between the red:far-red spectral ration in the canopy and leaf area index. *Ann. Bot.* 58, 207-219.

MSUYA, D.G., REUBEN, S.O.W.M., MBILINYI, L.B., MAERERE, A.P., MSOGOYA, T., MULUNGU, L.S. & MISANGU, R.N., 2005. Evaluation of field performance and storage of some tropical short-day onion (*Allium cepa* L.) cultivars. *W. Afr. J. Ecol.* 8, 10-18.

MULUNGU, L.S., REUBEN, S.O.W.M., NCHIMBI-MSOLLA, S., MISANGU, R.N., MBILINYI, L.B. & MACHA, M.M., 1998. Performance of nine exotic and local onion (*Allium cepa* L.) genotypes grown under a dry season tropical condition at Morogoro, Tanzania. 1. Yield and its components. *S. Afr. J. Sci.* 94, 451-454.

NASREEN, S., IMAMUL HAQ, S.M. & HOSSAIN, M.A., 2003. Sulphur effects on growth responses and yield of onion. *Asian J. Plant Sci.* 2, 897-903.

NOCK, C.A., CASPERSEN, J.P. & THOMAS, S.C., 2008. Large ontogenetic declines in intra-crown leaf area index in two temperate deciduous tree species. *Ecol.* 89, 744-753.

OKPORIE, E.O. & EKPE, I.I., 2008. Effect of photoperiod on the growth and bulbing of two tropical onion (*Allium cepa* L.) varieties. *W. J. Agric. Sci.* 4, 36-39.

PETERS, R.J., KOWITHAYAKORN, T., CHALARD, T. & RABINOWITCH, H.D., 1994. The effect of date of harvest on shelf life of onions stored by hanging from leaves. *Acta Hort.* 358, 365-368.

QUADIR, M.A. & BOULTON, A., 2005. Yield and maturity of new released red onion cultivars in New South Wales. *Acta Hort.* 694, 117-119.

RABINOWITCH, H.D., 1979. Doubling of onion bulbs as affected by size and planting date of sets. *Ann. Appl. Biol.* 93, 63-66.

RAMIN, A.A., 1999. Storage potential of bulb onions (*Allium cepa* L.) under high temperatures. *J. Hort. Sci. Biotechnol.* 74, 181-186.

RUMPEL, J. & FELCZYŃSKI, K., 2000. Effect of plant density on yield and bulb size of direct sown onions. *Acta Hort.* 533, 179-185.

SHANMUGASUNDARAM, S. & KALB, T., 2001. Suggested cultural practices for onion. AVRDC training guide. Shanhua, Taiwan. www.http://www.avrdc.org (Accessed on 15/10/11).

SINCLAIR, P., 1989. Physiology of the onion. *Aus. Onion Grower* 6, 7-9.

SOBEIH, W.Y. & WRIGHT, C.J., 1987. The photoperiodic regulation of bulbing in onions (*Allium cepa* L.). III. Response to red:far-red ratio and cyclic lighting. *J. Hort. Sci.* 62, 379-389.

SORENSEN, J.N. & GREVSEN, K., 2001. Sprouting in bulb onions (*Allium cepa* L.) as influenced by nitrogen and water stress. *J. Hort. Sci. Biotechnol.* 76, 501-506.

SORENSEN, J.N. & GREVSEN, K., 2002. Nitrogen and water stress affects sprouting in bulb onions stored over winter. *Acta Hort.* 571, 79-86.

STEER, B.T., 1980. The bulbing response to day length and temperature of some Australasian cultivars of onion (*Allium cepa* L.). *Aust. J. Agric. Res.* 31, 511-518.

SULLIVAN, D.M., BROWN, B.D., SHOCK, C.C., HORNECK, D.A., STEVENS, R.G., PELTER, G.Q. & FEIBERT, E.B.G., 2001. Nutrient management for onions in the Pacific North West. A Pacific Extension Publication No. 546. Oregon State University. Pacific North West, United States of America.

TANAKA, M., TAKEI, K., KOJIMA, M., SAKAKIBARA, H. & MORI, H., 2006. Auxin controls local cytokinin biosysnthesis in the nodal stem in apical dominance. *Plant J.* 45, 1028-1036.

THE NATIONAL AGRICULTURAL DIRECTORY, 2009. Field crops and horticulture. Vegetables. Department of Agriculture, Pretoria, South Africa.

UD-DEEN, M., 2008. Effect of mother bulb size and the planting time on growth, bulb and seed yield of onion. *Bangladesh J. Agric. Res.* 33, 531-537.

VALENZUELA, H., SHIMABUKU, R., KRATKY, B. & HAMASAKI, R., 1999. Onions in Hawaii and around the world. *In*: R. Hamasaki, H. Valenzuela & R. Shimabuka (eds.). Bulb production in Hawaii. College of Tropical Agriculture and Human Resources. Manoa, Hawaii.

VAN DEN BERG, A.A., DE WET, H. & COERTZE, A.F., 1997. Onion cultivars. Onions C.1. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

VOSS, R.E., MURRAY, M., MAYBERRY, K.S. & MILLER, I., 1999. Onion seed production in California. University of California, Division of Agriculture and Natural Resources. California. United States of America.

WEERASINGHE, S.S. & FORDHAM, R., 1994. The effects of plant density on onions established from multiseeded transplants. *Acta Hort.* 371, 97-104.

WICKRAMASINGHE, U.L., WRIGHT, C.J. & CURRAH, L., 2000. Bulbing responses of two cultivars of red tropical onions to photoperiod, light integral and temperature under controlled growth conditions. *J. Hort. Sci. Biotechnol.* 75, 304-311.

WILES, G.C., 1989. The effect of light and temperature on bulb initiation and development in tropical cultivars of onion (*Allium cepa* L.). Ph.D. thesis, Wye College University of London, London.

WILES, G.C., 1994. The effect of different photoperiods and temperatures following bulb initiation on bulb development in tropical onion cultivars. *Acta Hort.* 358, 419-427.

WRIGHT, P.J. & GRANT, D.G., 1997. Effects of cultural practices at harvest on onion bulb quality and incidence of rots in storage. *N. Z. J. Crop Hort. Sci.* 25, 353-358.

CHAPTER 3

MATERIALS AND METHODS

3.1 INTRODUCTION

Trials were conducted on the West Campus facility of the Department of Soil, Crop and Climate Sciences, University of the Free State in Bloemfontein during 2009 and 2010. Bloemfontein (29°06'S and 26°18'E, 1395 m above sea level) is located in the Central Free State on the southern edge of the Highveld. The area is located within the semi-arid climate of the revised Köppen Climate Classification (Kruger, 2004), with hot summer days (annual average maximum temperature of 24.4°C) and cold dry winters (annual average minimum temperature of 7.5°C) often with severe frost. It is a summer rainfall area with an annual average rainfall of 559 mm. Table 3.1 shows a summary of weather conditions during the two production seasons. Daily climate conditions of both seasons are given in Appendix 1.

Table 3.1: Monthly average maximum and minimum temperatures, photoperiod and total rainfall from weather station for 2009 and 2010 (Department of Metrological Services, 2010; South African Astronomical Observatory, 2009 & 2010; Weather Underground, 2010)

Month	Temperatures (°C)		Photoperiod (hours)	Rainfall (mm)
	Maximum	Minimum		
		2009		
January	30.28	16.60	13.45	120.90
February	26.67	16.15	13.31	97.80
March	27.17	13.60	12.05	21.30
April	24.97	10.55	11.24	11.90
May	20.00	5.84	10.39	20.60
June	16.38	4.18	10.18	27.40
July	15.71	-0.15	10.29	10.90
August	20.31	4.80	11.30	9.70
September	24.98	8.33	12.11	0.00
October	25.72	11.93	12.58	70.60
November	26.12	12.41	13.34	85.10
December	31.90	15.67	14.13	54.40
Average	**24.18**	**9.99**	**12.03**	**44.23**
Total Rainfall				**530.60**
		2010		
January	27.86	17.13	13.45	131.10
February	29.07	16.73	13.31	124.70
March	27.78	14.74	12.06	77.70
April	22.96	10.58	11.22	48.50
May	20.75	6.63	10.39	39.90
June	16.96	1.64	10.18	20.10
July	18.44	4.04	10.28	0.30
August	21.05	3.84	11.30	0.00
September	26.35	9.14	12.11	0.30
October	27.10	10.96	12.57	20.60
November	28.47	13.19	13.34	30.20
December	28.51	14.65	14.13	113.00
Average	**24.61**	**10.27**	**12.03**	**50.53**
Total Rainfall				**606.40**

3.2 FIELD TRIALS

3.2.1 Cultivar and sowing date

In the first experiment, conducted during 2009, four onion cultivars and three sowing dates were evaluated (Table 3.2). This was repeated in 2010 (Table 3.2) using the same number of cultivars and sowing dates. However, seed of 'South Wester' was no longer available and was replaced with 'Ceres Gold', which is also a mid-intermediate day cultivar (Hygrotech, 2009). Sowing dates were delayed in 2010 due to heavy rainfall and the availability of seed.

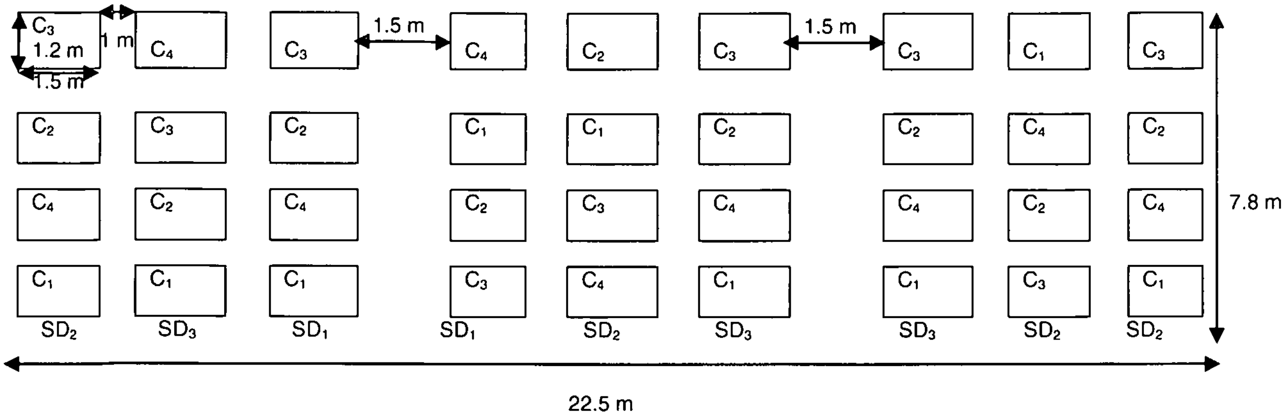
Table 3.2: Different onion cultivars and sowing date treatments used in 2009 and 2010

Cultivar	Type	Sowing Date	Plant spacing (cm)		Plant population		Plot size (m^{-2})	
			In row	Between row	m^{-2}	ha^{-1}	gross	net
			2009					
Charlize	Short day	30 April	8.0	30	41	416 667	1.8	0.79
Jaquar	Early-intermediate	07 May						
Python	Early-intermediate	21 May						
South Wester	Mid-intermediate							
			2010					
Charlize	Short day	11 May	5.5	30	61	606 061	1.8	0.88
Jaquar	Early-intermediate	25 May						
Python	Early-intermediate	08 June						
Ceres Gold	Mid-intermediate							

Both experiments were laid out in a randomized complete block design (Figure 3.1), with each treatment combination replicated three times. Plant population, spacing and plot size used in these two trials are indicated in Table 3.2. In each plot there were five rows and each row had fifteen plants during 2009 and twenty two plants during 2010. Plot lay out for 2009 is presented in Appendix 2, Figure 1 and for 2010 in Figure 2.

3.2.2 Sowing date and plant population

A field trial to evaluate three sowing dates and five plant populations (Table 3.3) using a single onion cultivar ('Jaquar') was conducted during 2010. This cultivar was selected as it gave the best performance during the 2009 season's experiment. The experiment was laid out as a randomized complete block design (Figure 3.2), with three replications. Plant spacing and plot dimensions are indicated in Table 3.3. In each plot there were five rows and each row had the number of plants as per required plant population (Table 3.3). Appendix 2, Figure 3a-e shows the lay out of plants in each plot.



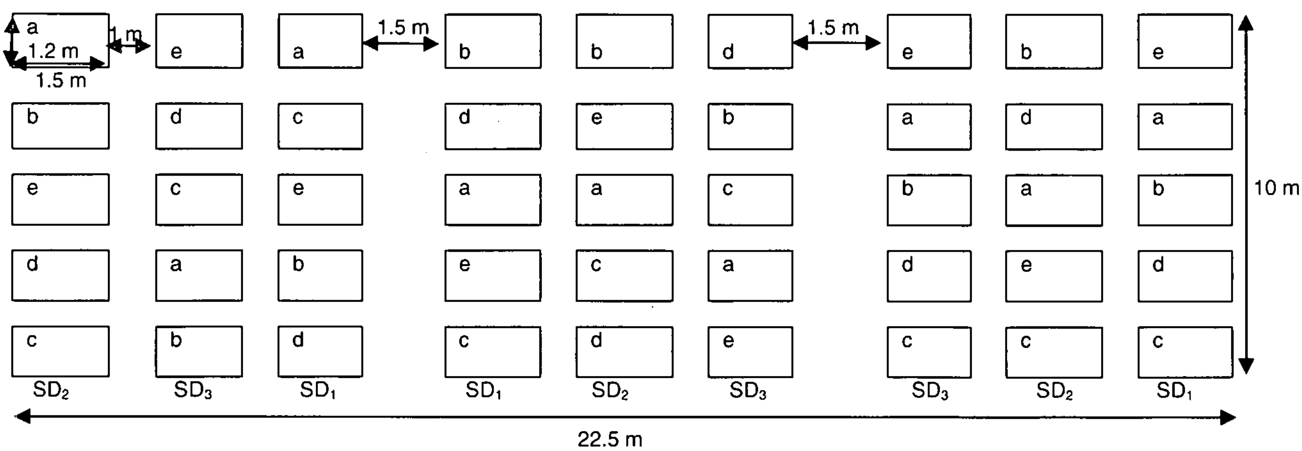
C_1 = Charlize, C_2 = South Wester, C_3 = Python and C_4 = Jaguar.

SD_1 = sowing date 30th April, SD_2 = sowing date 7th May and SD_3 = sowing date 21st May

Figure 3.1: Field trial layout to investigate the influence of sowing date and cultivar on onions

Table 3.3: Different sowing dates and plant population treatments

Plant spacing (cm)		Sowing	Plant population		Plot size (m^{-2})		Plants
In row	Between row	date	m^{-2}	ha^{-1}	gross	net	row^{-1}
3.5	30		95	952 381	1.8	0.95	34
4.0	30	11 May	83	833 333	1.8	0.94	30
4.5	30	25 May	74	740 741	1.8	0.92	26
5.0	30	08June	67	666 667	1.8	0.90	24
5.5	30		61	606 061	1.8	0.88	21



SD_1= sowing date 30th April, SD_2 = sowing date 07th May and SD_3= sowing date 21st May

a = 95 plants m^{-2}, b = 83 plants m^{-2}, c = 74 plants m^{-2}, d = 67 plants m^{-2}, e = 61 plants m^{-2}

Figure 3.2: Field trial layout to investigate the influence of sowing date and plant population on onion cv. Jaquar

3.3 FIELD PROCEDURES

Soil samples were collected from the top soil to a depth of 15 cm prior to land preparation. This was done following a zig-zag pattern over the trial area and thereafter samples were mixed, dried and send for analysis. This was done for 2009 and 2010. Soil analyses were conducted by the ARC Small Grain Institute (laboratory) at Bethlehem. The analyses were carried out according to standard methods of The Non-Affiliated Soil Analysis Work Committee (1990). Some chemical and physical properties of the soil of the two trial areas used in 2009 and 2010 are indicated in Table 3.4.

Table 3.4: Some chemical and physical characteristics of the experimental sites

Property	2009	2010
$pH_{(KCl)}$	5.5	4.7
Nutrients (mg kg^{-1})		
P (Bray 1)	20.2	28.1
K (NH_4OA_C)	154.7	233.8
Ca (NH_4OA_C)	1653	531
Mg (NH_4OA_C)	456.7	156.3
Na (NH_4OA_C)	18.1	10.7
CEC ($cmol_ckg^{-1}$)	12.48	4.73
Particle size distribution (%)		
Sand	54	67
Clay	15	12
Loam	31	21

Results of the analyses were used to determine nutrient requirements according to the nutrient withdrawal amounts for onions (FSSA, 2007) at a targeted yield of 70 t ha^{-1}. In 2009, phosphorus (94 kg P ha^{-1}) and nitrogen (282 kg N ha^{-1}) were broadcast and incorporated into the soil before sowing using 3:1:0 (30). All the potassium (280 kg K ha^{-1}) was applied before sowing as KCl. A split application of the residual nitrogen was done using urea at 6 (34 kg ha^{-1}) and 12 weeks (34 kg ha^{-1}) after sowing. During 2010, phosphorus (46 kg ha^{-1}) and nitrogen (138 kg N ha^{-1}) were broadcast and incorporated into the soil before sowing using 3.1.0 (28). All the potassium (280 kg K ha^{-1}) was applied before sowing using KCl. A split application of the residual nitrogen was done using urea at 6 (106 kg ha^{-1}) and 12 weeks (106 kg ha^{-1}) after sowing.

The soil was loosened to a depth of 30 cm with a disc plough, where after the seedbed was prepared using a rotovater. Further leveling was done manually with a rake for a fine and even seedbed. Before sowing the soil was watered to field capacity. Seeds were sown by hand and covered with soil to a depth of 2 cm. A light irrigation was applied after sowing, using a surface drip system with emitters spaced 30 cm in the line and with a delivery capacity of 2.1 L H_2O hr^{-1}. Irrigation (1.78 mm) was done on a daily basis, except on days that it rained, to prevent soil from forming a crust that would delay emergence (Mondal *et al.*, 1986). After emergence, irrigation (3.25 mm) was done every second day during the vegetative phase and daily (2.33 mm) from the start of bulb development until maturity.

Thinning plants to the required plant population took place three weeks after emergence. Weeds were controlled manually every week throughout the season. Sodium fluosilicate (Cutworm Bait) was broadcast at a rate of 10 g m^{-2} over the planting area after damage was noted during 2009. In 2010 the bait was applied as soon as the first seedlings emerged. Mercapthothin (Malasol) was applied at a rate of 17.5 ml 10 L^{-1} H_2O using a knapsack sprayer whenever aphids or thrips were noticed on the onion plants.

Onions were lifted by hand when 100% of the foliage top per plot had collapsed. If necessary, the soil was first loosened using a garden fork (Galmarini, 2000; Rumpel & Felczyński, 2000; Msuya *et al.*, 2005; Ibrahim & Adesiyun, 2009).

3.4 DATA COLLECTION

3.4.1 Growth parameters

Growth parameters were measured on eleven randomly selected plants located in the center of each plot. Data was collected every three weeks starting from the third week after emergence until 10% of the foliage collapsed.

3.4.1.1 Plant height

Plant height was measured from the ground level up to the tip of the highest leaf using a standard ruler.

3.4.1.2 Leaf number

The number of fully developed leaves (El Assi & Abu-Rayyan, 2007) were counted. Counting was done only on the active green leaves during data collection.

3.4.2 Bulb yield and quality parameters

Bulb yield (t ha^{-1}) and quality parameters were assessed on bulbs from the net plot size (Tables 3.2 and 3.3) of the middle rows in each plot. After harvesting, leaves and roots were cut from the bulbs, and bulbs cleaned by washing with water and dried with tissue paper.

3.4.2.1 Bulb fresh mass and yield

After harvesting, bulbs were weighed separately to obtain fresh mass per bulb of eleven randomly selected bulbs harvested from the net plot. The fresh mass of all bulbs harvested from net plot size will be expressed as g m^{-2}, and then converted to t ha^{-1} in order to indicate onion yield.

The same eleven bulbs randomly selected used for determining fresh mass were now used to measure the following quality parameters;

3.4.2.2 Bulb diameter

The diameter of bulbs was measured at right angles to the longitudinal axis at the widest circumference of the bulb using a digital caliper. Thereafter, the bulbs were graded according to South Africa's grading system (Table 3.5).

Table 3.5: Grading of onions in South Africa (Joubert & van der Klashorst, 1997)

Grade	Size (mm)
Extra small (XS)	10-34
Small (S)	35-39
Medium (M)	40-69
Large (L)	70-89
Extra large (XL)	>90

3.4.2.3 Neck diameter

The neck diameter was measured, 5 mm above the top of each bulb using a digital caliper.

3.4.2.4 Bulb defects

Bulb defects such as decay, split and mechanical damage were observed to aid in determining marketable bulbs. A scoring system used by the local fresh produce market was followed, i.e. Class 1 (excellent quality) no decay, no splits and no cracks; Class 2 (good quality) no decay, 5% splits and no cracks; Class 3 (fairly good) no decay, 5%

splits, 5% cracks and Class 4 (unmarketable) decay, exceeds 5% splits and severe cracks (M Klashorst, personal communication)[2].

3.4.2.5 Bulb shape

Bulb shape was determined by observation and classifying according to the description of Van den Berg *et al.* (1997) as shown in Figure 3.3.

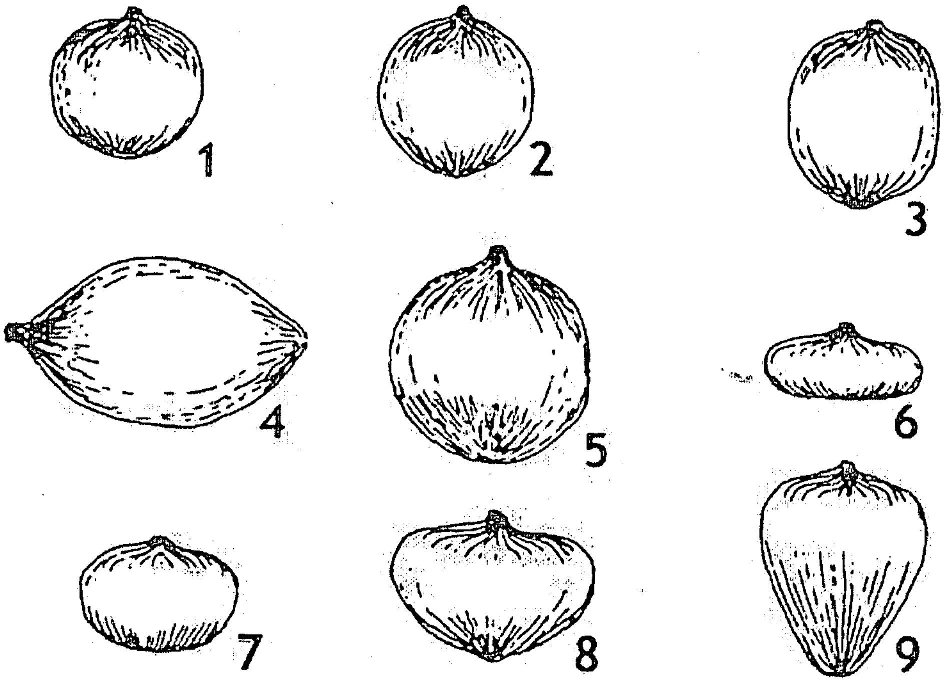


Figure 3.3: Different onion bulb shapes (1) Flattened (2) Globe (3) High globe (4) Spindle (5) Spanish (6) Flat (7) Thick flat (8) Granex (9) Top (Boyhan & Kelley, 2008)

3.4.2.6 Bulb firmness

Bulb firmness was measured using a Seta-Matic penetrometer controller (Model 1720), automatically controlled with a constant load penetrometer (Model 1719 of Stanhope seta Ltd., England) on the eleven bulbs selected. Onion bulbs were sliced in half from the neck to the base so that they would be stable when placed on the penetrometer table. The dryer outer scales of the bulbs were removed before puncturing bulbs. A constant load of 50 g was used to puncture the bulbs for 10 seconds and the depth of penetration recorded. Onion bulbs were punctured with the needle at three equidistant points around the largest circumference. The softer the bulbs, the deeper the needle penetrated the

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[2] Mr. M. Klashorst, 2011. Interaction market services Free State (Pty) Ltd t/a RSA market agents, P. O. Box 435, Bloemfontein, 9300

bulbs. The mean of the three measurements was used for statistical analysis (Charron *et al.*, 2001; Moretti *et al.,* 2005).

3.5 STORAGE

Twenty two randomly selected bulbs harvested from the net plot were used for the storage treatments. Bulbs were packed in knitted vegetable bags. Half (11 bulbs) were stored in a cold room (5°C) and the other half (11 bulbs) at room temperature (± 25°C). During 2010, before the storage process started, each bag was weighed. Thereafter, bulbs were weighed every three weeks to determine the amount of moisture lost. All diseased and sprouted bulbs were removed from the bags and recorded, and this was done to avoid contamination of the healthy bulbs (Chung, 1989; Getahun *et al.*, 2003; Msuya *et al.*, 2005). The final number of bulbs or bulb mass obtained at the last date of data collection was subtracted from the initial bulb number or mass. Thereafter, the difference was calculated as percentage lost. Storage of bulbs was terminated as soon as all the bulbs in the bag were no-longer consumable (visual appearance) and marketable.

3.6 STATISTICAL ANALYSIS

Analysis of variance was done on all measured parameters using the NCSS 2000 statistical program (Hintze, 1999), except where stated. Significance of differences between means of treatments was evaluated using Tukey's test for the LSD $\leq$ 0.05 (Turkey, 1953).

REFERENCES

BOYHAN, G. & KELLEY, W.T., 2008. Variety selection and characteristics. *In:* G.E. Boyhan & W.T. Kelley (eds.). Onion production guide. Cooperative Extension. The University of Georgia, Georgia, United States of America.

CHARRON, G., FURLAN, V., BERNIER-CARDOU, M. & DOYON, G., 2001. Response of onion plants to arbuscular mycorrhizae. 1. Effects of inoculation method and phosphorus fertilization on biomass and bulb firmness. *Mycorrhiza* 11, 187-197.

CHUNG, B., 1989. Irrigation and bulb onion quality. *Acta Hort.* 247, 233-237.

DEPARTMENT OF METEOROGICAL SERVICES, 2010. Monthly climatological summary. University of the Free State, Bloemfontein, South Africa.

EL ASSI, N. & ABU-RAYYAN, A., 2007. Yield and quality of onion bulbs as affected by manure applications. *Acta Hort.* 741, 265-271.

FSSA, 2007. Fertilizer handbook, 6th edn., FSSA, Pretoria. South Africa.

GALMARINI, C.R., 2000. Onion cultivars released by La Consulta experiment station, INTA, Argentina. *HortScience* 35, 1360-1362.

GETAHUN, D., ZELLEKE, A., DEROS, E. & KIFLU, E., 2003. Storability of shallot cultivars (*Allium cepa* L. var. *ascalonicum* Baker) at Debre Zeit, Ethiopia. *Acta Hort.* 604, 639-646.

HINTZE, J., 1999. Number cruncher statistical systems 2000. Kaysville, Utah.

HYGROTECH, 2009. Onion variety profiles: Intermediate day length. Hygrotech Sustainable Solutions. www.hygrotech.com (Accessed 10/05/09).

IBRAHIM, N.D. & ADESIYUN, A.A., 2009. Effects of staggered planting dates on the control of *Thrips tabaci* Lindeman and yield of onion in Nigeria. *Afr. J. Agric. Res.* 4, 33-39.

JOUBERT, T.G. LA G. & VAN DER KLASHORST, E., 1997. The marketing, grading and export of onions. Onions J.1. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

KRUGER, A.C., 2004. Climate of South Africa: climatic regions. South African Weather Service. Pretoria, South Africa.

MONDAL, M.F., BREWSTER, J.L., MORRIS, G.E.L. & BUTLER, H.A., 1986. Bulb development in onion (*Allium cepa* L.). I. Effects of plant density and sowing date in field conditions. *Ann. Bot.* 58, 187-195.

MORETTI, C.L., BERG, F.L.N., MATTOS, L.M., SANTOS, J.Z., SAMINÊZ, T.C.O., RESENDE, F.V., MENDONÇA, J.L. & LIMA, D.B., 2005. Chemical composition and physical properties of organically grown onions in central Brazil. *Acta Hort.* 688, 317-321.

MSUYA, D.G., REUBEN, S.O.W.M., MBILINYI, L.B., MAERERE, A.P., MSOGOYA, T., MULUNGU, L.S. & MISANGU, R.N., 2005. Evaluation of field performance and storage of some tropical short-day onion (*Allium cepa* L.) cultivars. *W. Afr. J. Ecol.* 8, 10-18.

RUMPEL, J. & FELCZYŃSKI, K., 2000. Effect of plant density on yield and bulb size of direct sown onions. *Acta Hort.* 533, 179-185.

SOUTH AFRICAN ASTRONOMICAL OBSERVATORY, 2009. Bloemfontein sunrise and sunset. www.saao.ac.za (accessed on 2/8/2011).

SOUTH AFRICAN ASTRONOMICAL OBSERVATORY, 2010. Bloemfontein sunrise and sunset. www.saao.ac.za (accessed on 2/8/2011).

THE NON-AFFILIATED SOIL ANALYSIS WORK COMMITTEE, 1990. Handbook of standard soil testing methods for advisory purposes. *Soil Sci. Soc. S. Afr.*, Pretoria, South Africa.

TURKEY, J.W. 1953. The problem of multiple comparisons. Department of Statistics, Princeton University, New York, United States of America.

VAN DEN BERG, A.A., DE WET, H. & COERTZE, A.F., 1997. Onion cultivars. Onions C.1. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

WEATHER UNDERGROUND, 2010. Weather forecast Bloemfontein, South Africa. www.wunderground.com (Accessed 04/05/09).

CHAPTER 4

RESPONSE OF ONION (*Allium cepa* L.) TO SOWING DATE

4.1 INTRODUCTION

Onion is a biennial plant but it is commonly grown in South Africa as an annual crop. The production cycle of onions involves vegetative growth, bulbing, flowering and seed production. Compared to other vegetable crops, onions grow very slowly during the seedling phase and can be as long as 2 to 3 months (Sullivan *et al.*, 2001; Brewster, 2008). During early growth and development, onions require cool temperatures (6-20°C) but during bulb initiation and development, warmer temperatures (25-27°C) are required (Comrie, 1997a; Ansari, 2007). Onions can be established through either transplanting of seedlings, sowing seed directly or planting onion sets. According to Brewster (2008) the yield of any crop is determined through the quality of light absorbed by the leaves, the efficiency with which the absorbed light is converted by photosynthesis into sucrose and the proportion of photosynthetic output transferred to the harvested fraction of the plant, which are the bulbs of onions.

Environmental conditions such as photoperiod and temperature control the progress from one developmental stage to another and also the growth rate and the number of days to maturity of onions. Lancaster *et al.* (1996) indicated that for bulb initiation a double threshold need to be attained. First a minimum day length for a specific cultivar is necessary but also the plant need to accumulate thermal time of approximately 600 degree days (growing degree days above 5°C) from emergence. Both these requirements need to be met before bulb initiation will occur. The leaves of the onion plant reacts on day length and as soon as the minimum day light length is reached the apical meristem no longer form leaves consisting out of a sheath and a blade but only sheaths (Brewster, 1994). It is these leaf sheaths that will swell and form the bulb contributing to the yield of onions (Quadir & Boulton, 2005). Onion cultivars classified as short day (SD) plants require a day length duration of 11-12 hours to initiate bulbs. Whereas onions classified as intermediate day (ID) cultivars start to initiate bulbs when day length is between 12-14 hours. Long day (LD) cultivars require a day length of more than 14 hours for bulb initiation and cannot be planted in South Africa because the longest average maximum day length is only 14.33 hours (Smith, 2006).

Even though photoperiod is vital for onion bulb initiation, plant size and temperature (Agic *et al.*, 2007) also influence bulb initiation. Although there is no minimum plant size for bulbing, larger plants tend to initiate bulbs earlier even though the required photoperiod is not met (Smittle, 1993). Very small plants do not respond to the bulbing stimulus as rapidly as larger plants (Butt, 1968 cited by Brewster, 1977). Larger plants are also more prone to the production of split or double bulbs which contribute to poor quality (Comrie, 1997a). High temperatures (25-27°C) accelerate bulb initiation causing it to occur at a slightly shorter day length than required for a specific cultivar (van den Berg *et al.*, 1997). Wurr *et al.* (1998) reported that bulbing was accelerated at 18°C and delayed at 12°C, suggesting that warmer climate causes earlier bulb formation. However, if bulbing is stimulated when plants are still small, leaf senescence will occur rapidly and small bulbs will be produced due to a small leaf area (Wickramasinghe *et al.*, 2000). Low temperatures (9-13°C) close to bulb formation will cause plants to bolt instead of forming bulbs even though day length is long enough for bulbing. This will result in lower yields of a poor quality (Richwine, 1990; Comrie, 1997a; Khokhar *et al.*, 2007).

Timing of sowing date is therefore important so that every developmental phase may occur at times when temperature is favourable for crop performance and high yields can be obtained. Msuya *et al.* (2005) reported that sowing date and cultivar selection play an important role in onion crop performance. When onions are sown too late, defects such as bolting, thick necks and double bulbs occur. On the other hand, onions that are sown too early will have a long growth period resulting in larger plants and when exposed to low temperatures (9-13°C) just before bulb formation will result in bolting instead of bulb formation. The best sowing date for onions in the Free State Province is early to mid-April for short day, and end April to mid-May for intermediate day cultivars (Comrie, 1997b; Hygrotech, 2009a & b).

New onion cultivars are released annually and such need to be evaluated for sowing date, yield, and quality in different production areas. It is also important for producers to be informed of new potential onion cultivars that may improve production. Therefore, the current study was carried out in order to determine the optimum sowing date for different onion cultivars under the existing climatic conditions of Bloemfontein, in the Central Free State.

4.2 RESULTS AND DISCUSSION

4.2.1 Growth parameters

Plant height and leaf number were recorded to determine the growth of onion plants as influenced by different sowing dates. Measurements were taken every three weeks commencing three weeks after emergence, and are presented in both table and graph form. Tables were used to indicate the $LSD_{T(0.05)}$ values for each week of measurement, while figures illustrate the growth response over the trial period.

4.2.1.1 Onion growth

The growth period of the different onion cultivars used in the two field trials are presented in Table 4.1. The expected bulb initiation date according to the day length requirement and also the date when the thermal time of 600 degree days was reached is indicated in Table 4.1. Thermal time was calculated from the emergence date using the equation discussed in Chapter 2, Section 2.5.1.4 (Lancaster *et al.*, 1996).

Table 4.1: Summary of the growth period of the different onion cultivars as influenced by sowing date during 2009 and 2010

Cultivar	Cultivar type	Required day length for bulb initiation (hours)	Sowing date	Emergence date	Sowing to emergence (days)	Thermal time (600 degree days)	Earliest expected bulb initiation date	Emergence to expected bulb initiation (days)	Average maximum day temperature from emergence to expected bulb initiation (°C)	Final plant height (cm)	Final leaf number	Harvesting date	Sowing to harvesting (days)	Yield (t ha^{-1})
							2009							
Charlize	Short day	11-12	30 Apr (end Apr)	25 May	26	07 Sep	13 Aug	81	16.9	58.58	9.00	11 Nov	196	30.76
			07 May (early May)	02 Jun	26	11 Sep	13 Aug	73	16.7	51.06	7.67	18 Nov	196	26.37
			21 May (end May)	18 Jun	28	20 Sep	13 Aug	57	16.5	55.07	7.67	22 Nov	186	24.09
aquar	Early-intermediate	12-14	30 Apr (end Apr)	11 May	11	29 Aug	19 Sep	132	18.9	72.11	9.33	11 Nov	196	32.73
			07 May (early May)	18 May	11	02 Sept	19 Sep	125	18.8	64.35	8.35	18 Nov	196	29.56
			21 May (end May)	11 Jun	21	15 Sept	19 Sep	101	18.9	63.22	8.67	22 Nov	186	29.83
Python	Early-intermediate	12-14	30 Apr (end Apr)	11 May	11	29 Aug	19 Sep	132	18.9	74.26	8.67	16 Nov	201	23.22
			07 May (early May)	18 May	11	02 Sep	19 Sep	125	18.8	67.60	9.00	23 Nov	201	20.68
			21 May (end May)	11 Jun	21	15 Sep	19 Sep	101	18.9	82.86	9.00	23 Nov	187	22.72
South Wester	Mid-intermediate	12-14	30 Apr (end Apr)	13 May	13	30 Aug	19 Sep	130	18.8	54.67	8.35	12 Jan	258	32.09
			07 May (early May)	22 May	15	05 Sep	19 Sep	121	18.8	57.31	7.67	12 Jan	251	31.09
			21 May (end May)	14 Jun	24	17 Sep	19 Sep	98	18.9	68.93	8.67	12 Jan	237	19.95
							2010							
Charlize	Short day	11-12	11 May (early May)	24 May	13	31 Aug	13 Aug	82	18.1	47.64	7.33	08 Nov	182	40.13
			25 May (end May)	14 Jun	20	10 Sep	13 Aug	61	18.1	51.99	7.67	08 Nov	167	38.65
			08 Jun (early Jun)	06 Jul	28	17 Sep	13 Aug	39	18.7	43.00	7.33	15 Nov	161	26.28
aquar	Early-intermediate	12-14	11 May (early May)	24 May	13	31 Aug	19 Sep	118	20.1	54.97	7.33	08 Nov	182	40.45
			25 May (end May)	14 Jun	20	10 Sep	19 Sep	97	20.5	57.35	8.00	08 Nov	167	37.76
			08 Jun (early Jun)	06 Jul	28	17 Sep	19 Sep	76	21.6	44.58	7.33	15 Nov	161	31.10
Python	Early-intermediate	12-14	11 May (early May)	24 May	13	31 Aug	19 Sep	118	20.1	56.21	8.00	22 Nov	196	42.47
			25 May (end May)	14 Jun	20	10 Sep	19 Sep	97	20.5	60.15	8.00	22 Nov	182	29.71
			08 Jun (early Jun)	06 Jul	28	17 Sep	19 Sep	76	21.6	53.64	8.00	26 Nov	172	29.10
Ceres Gold	Mid-intermediate	12-14	11 May (early May)	24 May	13	31 Aug	19 Sep	118	20.1	42.48	7.00	05 Jan	240	40.79
			25 May (end May)	14 Jun	20	10 Sep	19 Sep	97	20.5	48.39	7.75	05 Jan	226	30.06
			08 Jun (early Jun)	06 Jul	28	17 Sep	19 Sep	76	21.6	39.00	7.00	05 Jan	212	26.32

4.2.1.2 Plant height

2009 season

The interaction between cultivar and sowing date did not significantly influence the height of onion plants over the entire period. Both cultivar and sowing date affected the plant height of onions significantly at three weeks after emergence (Table 4.2). 'Charlize' plants were significantly shorter (3.30 cm) than 'Python' (4.69 cm) and 'Jaquar' (4.66 cm). Plant height of 'South Wester' however, did not differ significantly from the other cultivars.

Table 4.2: Influence of sowing date on plant height (cm) of different onion cultivars from 3 to 18 weeks after emergence during 2009

Cultivar (C)	Sowing Date (SD)			Average (C)
	30 April	7 May	21 May	
		3 weeks after emergence		
Charlize	3.19	3.19	3.51	3.30
Jaquar	5.00	4.33	4.64	4.66
Python	5.15	4.67	4.24	4.69
South Wester	4.81	4.11	3.12	4.01
Average (SD)	4.54	4.08	3.88	
$LSD_{T(0.05)}$	C = 0.82	SD = 0.64	C x SD = ns	
		6 weeks after emergence		
Charlize	7.63	5.39	4.33	5.78
Jaquar	11.70	7.92	6.43	8.68
Python	10.44	9.43	7.33	9.07
South Wester	9.44	7.00	5.73	7.39
Average (SD)	9.80	7.44	5.96	
$LSD_{T(0.05)}$	C = 1.11	SD = 0.78	C x SD = ns	
		9 weeks after emergence		
Charlize	9.22	8.09	8.22	8.51
Jaquar	11.83	9.74	9.93	10.50
Python	13.01	10.72	12.57	12.10
South Wester	11.73	8.97	10.49	10.40
Average (SD)	11.45	9.38	10.30	
$LSD_{T(0.05)}$	C = 1.97	SD = 1.54	C x SD = ns	
		12 weeks after emergence		
Charlize	10.95	9.60	14.70	11.75
Jaquar	13.86	10.29	18.18	14.11
Python	15.78	13.13	22.97	17.29
South Wester	13.58	9.70	19.85	14.38
Average (SD)	13.54	10.68	18.93	
$LSD_{T(0.05)}$	C = 3.91	SD = 3.06	C x SD = ns	
		15 weeks after emergence		
Charlize	21.32	37.72	39.87	32.97
Jaquar	22.35	42.15	55.34	39.95
Python	26.52	46.24	60.08	44.28
South Wester	27.25	36.39	48.60	37.41
Average (SD)	24.36	40.63	50.97	
$LSD_{T(0.05)}$	C = 10	SD = 7.83	C x SD = ns	
		18 weeks after emergence		
Charlize	58.58	51.06	55.07	54.90
Jaquar	72.11	64.35	63.22	66.56
Python	74.26	67.60	82.86	74.91
South Wester	54.67	57.31	68.93	60.30
Average (SD)	64.91	60.08	67.52	
$LSD_{T(0.05)}$	C = 14.08	SD = ns	C x SD = ns	

Onion plants sown at the end of May, three weeks after emergence, were significantly shorter (3.88 cm) than those sown earlier on at the end of April (4.54 cm), but the height of onion plants sown in early May did not differ significant from plants sown on the other two dates.

The results obtained six weeks after emergence indicated that 'Charlize' plants were now not only significantly shorter than 'Python' and 'Jaquar' but also 'South Wester' plants. Onion plants sown early (30 April or 7 May) were significantly taller (9.80 cm or 7.44 cm) than those sown later on the 21^{th} May (5.96 cm).

'Python' and 'Jaquar' plants were still significantly taller than 'Charlize' plants nine weeks after emergence, and plant height of 'South Wester' were no longer different from any of the other cultivars. Onion plants sown on 30 April were no longer significantly taller than those sown on 21 May. Interestingly, onion plants sown on 7 May were now significantly shorter than those sown on 30 April.

At 12 weeks after emergence, the height of plants from the different onion cultivars still differed significantly from each other, although 'Charlize' plants were now only significantly shorter (11.75 cm) than those of 'Python' (17.29 cm). This was also true for the next few weeks up to the final week of data collection (18 weeks after emergence).

Onion plants that were sown late (21 May) were now significantly taller (18.93 cm) than plants from earlier plantings, 30 April (13.54 cm) or 7 May (10.68 cm) at 12 weeks after emergence. At 15 weeks after emergence, onion plants sown on 21 May (50.97 cm) or on 7 May (40.63 cm) both were now significantly taller than those plants sown on 30 April (24.36 cm). However, onions that were sown 30 May were now also significantly shorter than those sown on 7 May. This significant difference in plant height between onion plants sown on different dates was no longer evident late in the growing season (18 weeks after emergence).

2010 season

The interaction between cultivar and sowing date did not affect onion plant height over the entire data collection period (Table 4.3). Sowing date had a significant effect on onion plant height over almost the entire season and plant height of the cultivars only differed significantly from each other from week nine onwards.

Plant height of the different onion cultivars did not show a clear trend towards their response to different sowing dates over the entire measuring period (Table 4.3). 'Python' plants were significantly taller than 'Ceres Gold' plants from 9 to 12 weeks after emergence, whereas the other cultivar's plant heights did not differ from each other. 'Jaquar' and 'Python' plants were significantly taller than 'Ceres Gold' plants 15 weeks after emergence, while 'Charlize' plants were significantly shorter than 'Python' plants. At 18 weeks after emergence, 'Charlize', 'Python' and 'Jaquar' plants were significantly taller than those of 'Ceres Gold'.

Table 4.3: Influence of sowing date on the plant height (cm) of different onion cultivars from 3 to 18 weeks after emergence during 2010

Cultivar (C)	Sowing Date (SD)			Average (C)
	11 May	25 May	8 June	
		3 weeks after emergence		
Charlize	4.12	3.84	3.00	3.65
Jaquar	4.00	3.88	3.03	3.64
Python	4.42	4.06	3.09	3.86
Ceres Gold	4.06	3.79	3.00	3.62
Average (SD)	4.15	3.89	3.03	
$LSD_{T(0.05)}$	C = ns	SD = 0.22	C x SD = ns	
		6 weeks after emergence		
Charlize	7.73	5.76	6.70	6.73
Jaquar	8.21	5.76	7.79	7.25
Python	9.21	5.73	8.36	7.77
Ceres Gold	6.64	4.88	7.76	6.43
Average (SD)	7.95	5.53	7.65	
$LSD_{T(0.05)}$	C = ns	SD = 1.11	C x SD = ns	
		9 weeks after emergence		
Charlize	9.45	8.18	9.00	8.88
Jaquar	9.73	7.91	9.88	9.17
Python	11.09	8.12	10.00	9.74
Ceres Gold	8.21	6.33	9.94	8.16
Average (SD)	9.62	7.64	9.71	
$LSD_{T(0.05)}$	C = 1.28	SD = 1.00	C x SD = ns	
		12 weeks after emergence		
Charlize	14.03	11.97	11.57	12.52
Jaquar	12.18	12.92	11.91	12.34
Python	14.48	13.45	11.48	13.14
Ceres Gold	10.79	11.30	11.67	11.25
Average (SD)	12.87	12.41	11.66	
$LSD_{T(0.05)}$	C = 1.77	SD = ns	C x SD = ns	
		15 weeks after emergence		
Charlize	27.06	27.31	21.49	25.28
Jaquar	25.64	33.88	23.94	27.82
Python	31.03	33.88	24.30	29.74
Ceres Gold	22.43	28.57	19.70	23.57
Average (SD)	26.54	30.91	22.36	
$LSD_{T(0.05)}$	C = 4.02	SD = 3.15	C x SD = ns	
		18 weeks after emergence		
Charlize	47.64	51.91	43.00	47.52
Jaquar	54.97	57.33	44.58	52.29
Python	56.21	60.15	53.64	56.67
Ceres Gold	42.48	48.39	39.00	43.29
Average (SD)	50.33	54.45	45.05	
$LSD_{T(0.05)}$	C = 2.72	SD = 2.13	C x SD = ns	

Significantly taller onion plants were recorded when sown on 11 May (4.15 cm) or 25 May (3.89 cm) than those plants sown on 8 June (3.03 cm) at three weeks after emergence. However, at 6 and 9 weeks after emergence, onion plants that were sown on 25 May were now significantly shorter than those sown earlier (11 May) or later (8 June). Late in the season (15 and 18 weeks after emergence) the picture somewhat changed again. Onion plants sown on 25 May were now significantly taller than plants sown on 11 May or 8 June, 15 weeks after emergence. Both early sowings (11 May and 25 May) produced onion plants that were significantly taller than plants that were sown late (8 June) at the end of the data collection period (18 weeks after emergence).

4.2.1.3 Leaf number

2009 season

The interaction between cultivar and sowing date was only significant three weeks after emergence (Table 4.4) showing that onion cultivars reacted differently to sowing date. It was only 'Charlize' plants that produced significantly less leaves when sown 21 May than on 7 May (1.33) or 30 April (1.00). All the other onion cultivars produced the same number of leaves (2.00), irrespective of the sowing date. Neither cultivar nor sowing date had a consistent effect on the number of leaves produced by onion plants. At 6 and 12 weeks after emergence, significantly more leaves were produced by onion plants sown early (30 April) or late (21 May) than those sown on the 7th May.

'Jaquar' plants produced significantly more leaves (2.56) than 'South Wester' (2.00) and 'Charlize' (2.00) plants six weeks after emergence. The number of leaves produced by 'Charlize' (2.00), 'South Wester' (2.00) and 'Python' (2.33) plants however, did not differ from each other. Fifteen weeks after emergence only 'Python' plants produced significantly more leaves (7.89) than 'Charlize' (6.45) and the number of leaves produced by the other cultivars did not differ significantly from each other. At the final measuring date (18 weeks after emergence), the number of onion leaves produced was not significantly influenced by either cultivar or sowing date.

Table 4.4: Influence of sowing date on leaf number of different onion cultivars from 3 to 18 weeks after emergence during 2009

Cultivar (C)	Sowing Date (SD)			Average (C)
	30 April	7 May	21 May	
		3 weeks after emergence		
Charlize	1.33	1.00	2.00	1.44
Jaquar	2.00	2.00	2.00	2.00
Python	2.00	2.00	2.00	2.00
South Wester	2.00	2.00	2.00	2.00
Average (SD)	1.83	1.75	2.00	
$LSD_{T(0.05)}$	C = 0.22	SD = 0.71	C x SD = 0.50	
		6 weeks after emergence		
Charlize	2.00	2.00	2.00	2.00
Jaquar	3.00	2.00	2.67	2.56
Python	2.33	2.00	2.67	2.33
South Wester	2.00	2.00	2.00	2.00
Average (SD)	2.33	2.00	2.34	
$LSD_{T(0.05)}$	C = 0.39	SD = 0.30	C x SD = ns	
		9 weeks after emergence		
Charlize	2.33	2.33	2.00	2.22
Jaquar	3.00	2.33	3.00	2.78
Python	3.00	2.33	3.00	2.78
South Wester	2.33	2.33	2.67	2.44
Average (SD)	2.67	2.33	2.67	
$LSD_{T(0.05)}$	C = ns	SD = ns	C x SD = ns	
		12 weeks after emergence		
Charlize	3.00	2.67	3.67	3.11
Jaquar	3.67	3.00	3.67	3.45
Python	3.67	3.00	4.00	3.56
South Wester	3.67	3.00	3.67	3.45
Average (SD)	3.50	2.92	3.75	
$LSD_{T(0.05)}$	C = ns	SD = 0.46	C x SD = ns	
		15 weeks after emergence		
Charlize	6.67	6.67	6.00	6.45
Jaquar	8.67	7.00	6.33	7.33
Python	8.00	8.00	7.67	7.89
South Wester	7.33	6.67	7.33	7.11
Average (SD)	7.67	7.09	6.83	
$LSD_{T(0.05)}$	C = 1.41	SD = ns	C x SD = ns	
		18 weeks after emergence		
Charlize	9.00	7.67	7.67	8.11
Jaquar	9.33	8.33	8.67	8.78
Python	8.67	9.00	9.00	8.89
South Wester	8.33	7.67	8.67	8.22
Average (SD)	8.83	8.17	8.50	
$LSD_{T(0.05)}$	C = ns	SD = ns	C x SD = ns	

2010 season

From data collected it is clear that the interaction between cultivar and sowing date did not significantly influence the number of leaves produced (Table 4.5). Sowing date also did not have such a major effect on the number of onion leaves produced per plant. It was only at 12 weeks after emergence that the early sown plants (11 May) produced significantly more leaves (3.75) than those sown later (25 May or 8 June) with 3 or 3.08 leaves respectively. This trend, however, did not continue later on in the growth season. Late in the vegetative growth phase (15 and 18 weeks after emergence) cultivar differences in the number of leaves produced per plant came to the fore.

Table 4.5: Influence of sowing date on leaf number of different onion cultivars from 3 to 18 weeks after emergence during 2010

Cultivar (C)	Sowing Date (SD)			Average (C)
	11 May	25 May	8 June	
		3 weeks after emergence		
Charlize	1.00	1.67	1.00	1.22
Jaquar	1.33	1.33	1.33	1.33
Python	1.67	1.67	1.67	1.67
Ceres Gold	1.00	1.00	1.67	1.22
Average (SD)	1.25	1.42	1.42	
$LSD_{T(0.05)}$	C = ns	SD = ns	C x SD = ns	
		6 weeks after emergence		
Charlize	1.67	1.67	1.67	1.67
Jaquar	2.00	1.67	1.33	1.67
Python	2.00	1.67	1.67	1.78
Ceres Gold	1.33	1.33	2.00	1.55
Average (SD)	1.75	1.59	1.67	
$LSD_{T(0.05)}$	C = ns	SD = ns	C x SD = ns	
		9 weeks after emergence		
Charlize	2.33	2.67	2.67	2.56
Jaquar	2.33	2.67	2.67	2.56
Python	3.00	2.33	2.67	2.67
Ceres Gold	2.67	2.33	2.33	2.44
Average (SD)	2.58	2.50	2.59	
$LSD_{T(0.05)}$	C = ns	SD = ns	C x SD = ns	
		12 weeks after emergence		
Charlize	3.67	3.00	3.33	3.33
Jaquar	4.00	3.00	3.00	3.33
Python	4.00	3.00	3.00	3.33
Ceres Gold	3.33	3.00	3.00	3.11
Average (SD)	3.75	3.00	3.08	
$LSD_{T(0.05)}$	C = ns	SD = 0.28	C x SD = ns	
		15 weeks after emergence		
Charlize	6.00	5.67	6.67	6.11
Jaquar	5.67	5.00	5.33	5.33
Python	7.00	6.00	5.33	6.11
Ceres Gold	5.33	4.33	5.00	4.89
Average (SD)	6.00	5.25	5.58	
$LSD_{T(0.05)}$	C = 0.99	SD = ns	C x SD = ns	
		18 weeks after emergence		
Charlize	7.33	7.67	7.33	7.44
Jaquar	7.33	8.00	7.33	7.55
Python	8.00	8.00	8.00	8.00
Ceres Gold	7.00	7.33	7.00	7.11
Average (SD)	7.42	7.75	7.42	
$LSD_{T(0.05)}$	C = 0.55	SD = ns	C x SD = ns	

At 15 weeks after emergence, 'Charlize' and 'Python' plants produced significantly more leaves (6.11 each) than those of 'Ceres Gold' (4.89), while the number of leaves produced by 'Jaquar' plants (5.33) did not differ significantly from any of the other cultivars. 'Python' plants produced significantly more leaves (8.00) than 'Ceres Gold' (7.11) and 'Charlize' (7.44) plants 18 weeks after emergence.

The phenomenon that onions grow very slowly during the early seedling phase, almost twice as long as cabbage or lettuce (Brewster, 2008) was also observed in this study for all the onion cultivars during both seasons (2009 and 2010). Plant height (Figure 4.1) and leaf number (Figure 4.2) increased at a slow rate during the first 12 weeks after emergence.

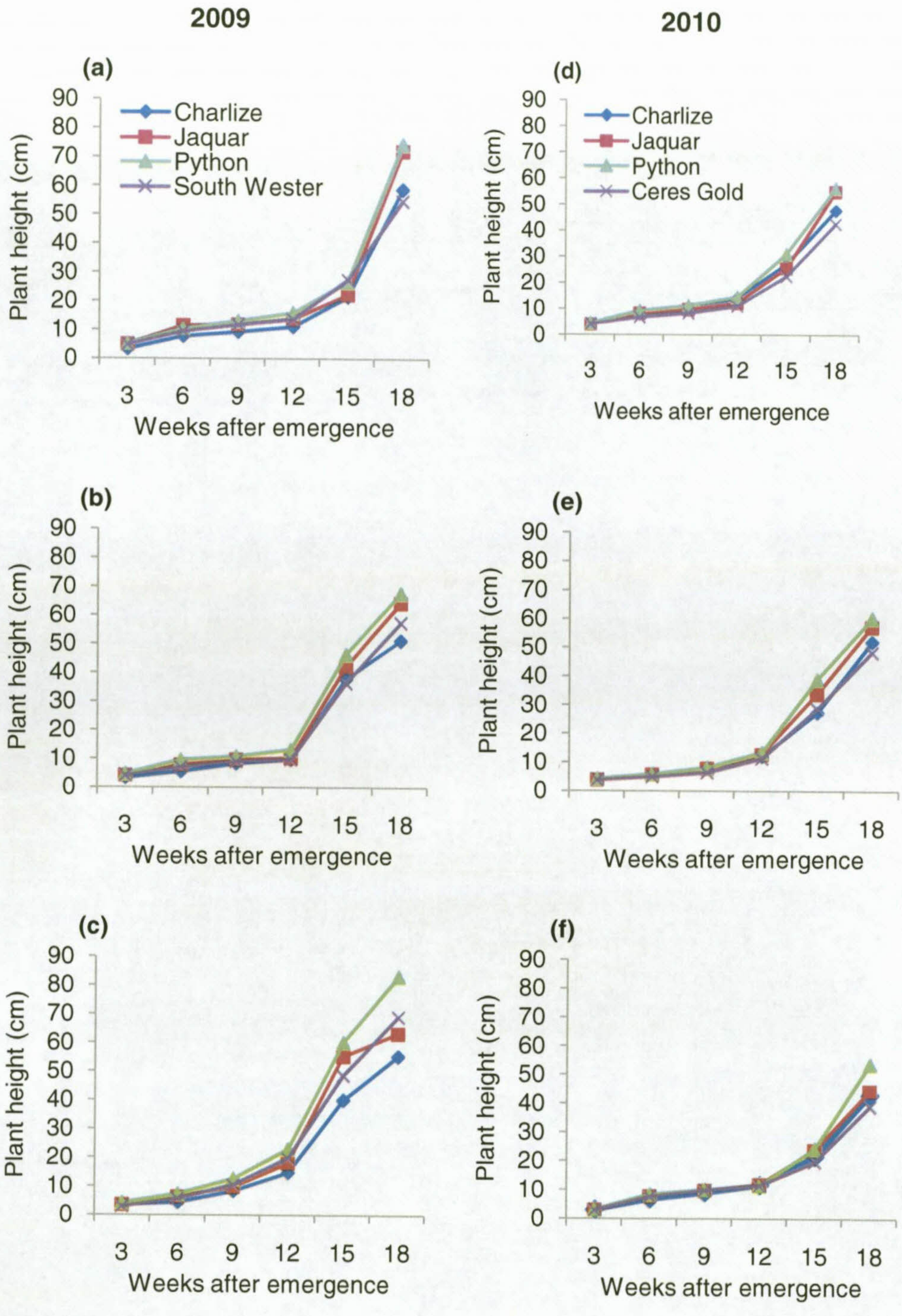


Figure 4.1: Plant height as influenced by sowing date of different onion cultivars when sown on (a) 30 April, (b) 7 May and (c) 21 May during 2009 and on (d) 11 May, (e) 25 May and (f) 08 June during 2010, from 3 up to 18 weeks after emergence

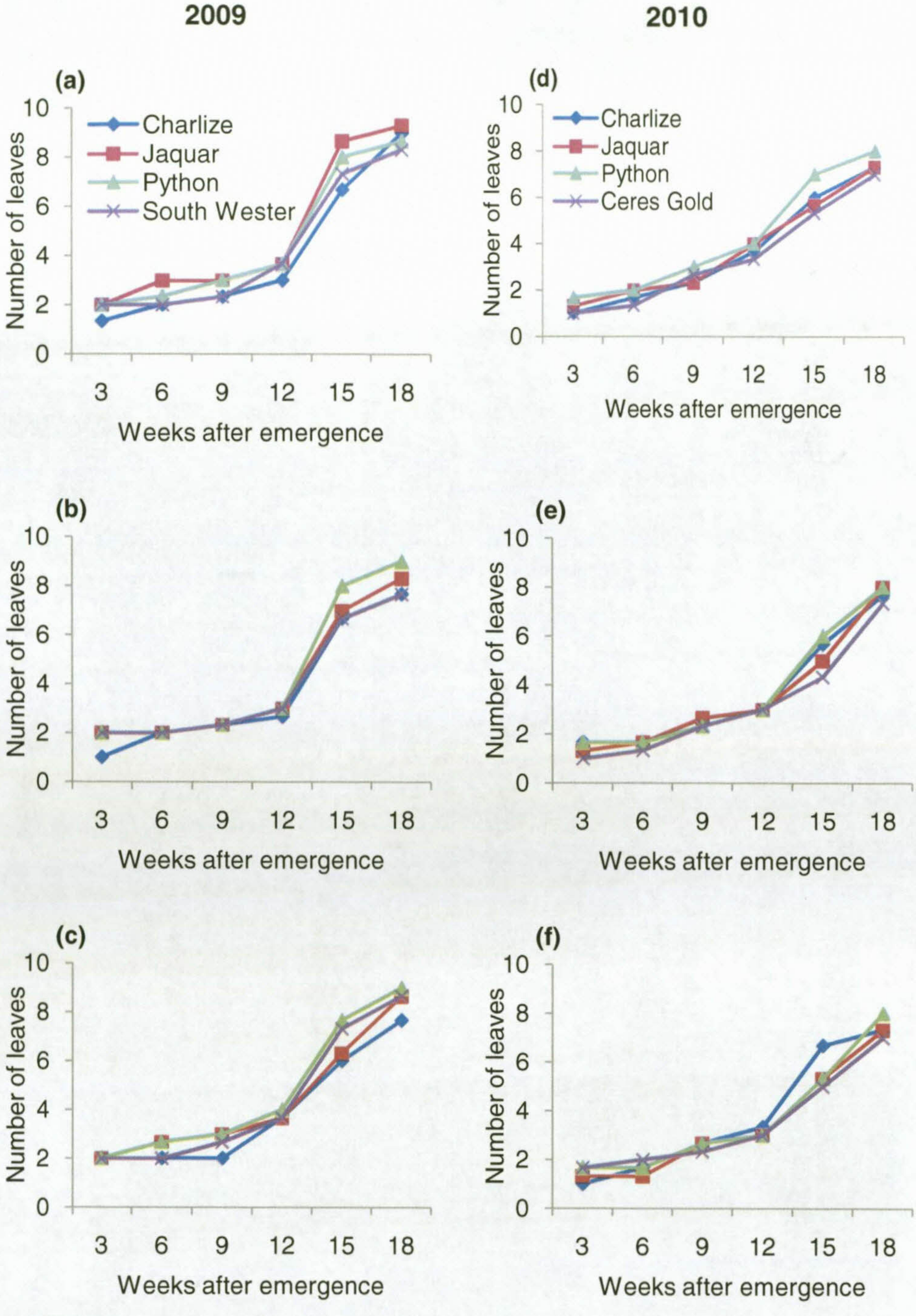


Figure 4.2: Leaf number of different onion cultivars as influenced by sowing date when sown on (a) 30 April, (b) 07 May and (c) 21 May during 2009 and on (d) 11 May, (e) 25 May and (f) 08 June during 2010, from 3 up to 18 weeks after emergence

The average maximum temperature for this period (May to July) ranged between 15.7°C and 20.8°C (Table 3.1). A sharp increase in onion plant height (Figure 4.1) and leaf number (Figure 4.2) was observed from week 12 after emergence (October for 2009 when sown on 30 April or 7 May and November when sown 21 May). The same trend was noted at week 12 after emergence during 2010 (October when sown on 11 May and November when sown on 25 May or 8 June). The average maximum temperature increased during this period and ranged between 20.3-31.9°C (Table 3.1).

A positive correlation between temperature and onion plant height were obtained ranging between 75% and 79% in 2009 and 64% and 69% in 2010. A somewhat weaker, but still positive, correlation was observed between temperature and onion leaf number, ranging between 63% and 80% in 2009 and 67% and 77% in 2010. The average maximum day temperature from emergence to expected onion bulb initiation (Table 4.1) was higher during 2010 (18.1-21.6°C) than during 2009 (16.5-18.9°C) and may be the reason for the weaker correlations during 2010. As was indicated earlier, onions prefer a cooler temperature (<20°C) for vegetative growth.

Literature indicates that photoperiod is associated more with bulbing of onions (Steer, 1980; Mondal *et al.*, 1986; Wickramasinghe *et al.*, 2000) than with vegetative growth (Okporie & Ekpe, 2008). However, the current results revealed a strong positive correlation between photoperiod and onion plant height and leaf number. In 2009 the correlation between onion plant height and photoperiod ranged between 82 and 90%, and 64 and 68% in 2010. For onion leaf number correlations of between 69 and 85% in 2009 and 67 to 78% in 2010 were obtained.

According to Brewster (1994) as soon as the required minimum day length of an onion cultivar is met and temperatures start to increase, bulbs will be initiated. Therefore, when the same cultivar is sown at different times in the same area, plants will start forming bulbs at more or less the same time. Thus, those that are sown earlier will have a longer vegetative growth period than those sown later. This was also true in the current study as the growth period of onions sown late was shorter than those sown early (Table 4.1). This then results in larger plants with more leaves for early sown plants (Comrie, 1997b). Lancaster *et al.* (1996) reported that 'Pukekohe Longkeeper' and 'Early Longkeeper' produced more leaves (16.5 and 16.1, respectively) when sown early, and when sown late the number of leaves decreased to 12.9 for 'Pukekohe Longkeeper' and 10.8 for 'Early Longkeeper'. However, in the current study sowing date did not significantly influence production of leaves (Table 4.4 and 4.5).

Planting date did not have such a prominent effect on final plant height and number of leaves of onions in this study. In 2009, only 'Jaquar' plants showed a decline in plant height with a delay in sowing date (Table 4.2), although this was not significant. 'Jaquar' plants that were sown on 30 April had a growth period from emergence to expected bulb initiation of 132 days with an average day temperature of 18.9°C. 'Jaquar' plants sown on the 7 or 21 May had a growth period of 125 and 101 days, respectively and the average maximum temperature ranged between 18.8°C and 18.9°C. 'Charlize' plants on the other hand also produced the highest plants when sown early (30 April) having a growth period of 81 days from emergence to expected bulb initiation. 'Charlize' sown late on 21 May, had the shortest growth period (57 day) but were taller than those plants sown earlier on 7 May with a longer growth period of 73 days. The average maximum day temperatures for these different sowing dates were almost the same and ranged between 16.5°C and 16.9°C. 'South Wester' and 'Python' performed the best when sown later on 21 May, although these plants had the shortest growth period of 98 and 101 days, respectively. The average maximum temperatures for the different sowing dates were almost the same and ranged between 18.8°C and 18.9°C (Table 4.1).

Plants of all the onion cultivars were tallest when sown on 25 May, followed by 11 May and 8 June in 2010. Although early sown plants (11 May) had a longer growth period, between 82 and 118 days from emergence to bulb initiation, and the average maximum temperature ranged between 18.1°C and 20.1°C, plants were not taller than those plants sown on 25 May. These plants experienced a shorter growth period of between 61 and 97 days and average maximum temperatures of between 18.0°C and 20.5°C which was almost the same as for plants sown earlier. Interestingly, in most cases the tallest plants also produced the most number of leaves during both seasons (Table 4.1). Aliyu *et al.* (2007) also reported that onion plant height correlate with leaf number.

Msuya *et al.* (2005) and Brewster (2008) reported that the growth of various onion cultivars differs, and will not be the same due to differences in genotype. Present results also indicated that cultivars performed differently regarding their growth habit. 'Python' (early-intermediate day cultivar) produced significantly taller plants than 'Charlize' (short day cultivar), 'South Wester' and 'Ceres Gold' (two mid-intermediate day cultivars) in both seasons. However, 'Python' plants were also significantly taller than those of 'Jaquar' during 2010 but not in 2009. The same trend was observed for the number leaves, although during 2009 there was no significant difference in leaf number of plants from different cultivars. In 2010, 'Ceres Gold' plants were significantly shorter plants than those of all the other cultivars.

When considering the growth parameters, the recommended sowing date for the Bloemfontein area for all the cultivars studied, will therefore be from the end of April up to the end of May. However, the question now arises as to whether this same recommended dates will also be applicable when considering yield and quality data for the different onion cultivars.

4.2.2 Bulb yield and quality parameters

4.2.2.1 Bulb fresh mass and yield

2009 and 2010 seasons

None of the factors studied significantly affected onion bulb fresh mass (g $bulb^{-1}$) and total yield (t ha^{-1}) during 2009 (Tables 4.6 and 4.7). Even though there was no significant differences in bulb fresh mass between onion cultivars, 'Jaquar' bulbs were the heaviest (73.51 g) followed by 'South Wester' (66.35 g), 'Charlize' (64.82 g) and then 'Python' (53.16 g) (Table 4.6). Bulb fresh mass of onion plants sown the earliest on 30 April were the heaviest (71.11 g) followed by those bulbs of plants sown on 7 May (64.45 g) and 21 May (57.82 g), although not significant (Table 4.6). As can be expected, onion yield showed the same trend as for bulb fresh mass (Table 4.7).

In 2010, however, both yield parameters were significantly influenced by sowing date (Tables 4.6 and 4.7). Even though there were no significant differences in bulb fresh mass between onion cultivars, 'Jaquar' bulbs were again the heaviest (63.59 g) followed by 'Charlize' (61.12 g), 'Python' (58.92 g) and 'Ceres Gold' (56.52 g) (Table 4.6). Onion bulb fresh mass tended to be lower with delayed sowing dates, although the difference was not always significant. Significantly heavier onion bulbs were harvested when plants were sown early (11 May) than when sown later (25 May or 8 June). Onion bulb fresh mass of plants sown on the two later dates did not differ significantly from each other. As shown in Table 4.7 bulb yield followed the same trend.

Onion bulb mass and yield did not differ significantly between the different onion cultivars in both seasons. Sowing date also had no significant effect on these parameters during 2009 when sowing started on 30 April and ended on 21 May. During 2010, however, sowing date did have a significant effect on bulb fresh mass and yield when sowing started on 11 May and ended later on 8 June. It is clear that a delayed sowing date, from mid May to beginning of June, affected onion yield negatively.

Table 4.6: Influence of sowing date on bulb fresh mass (g bulb^{-1}) of different onion cultivars during 2009 and 2010

Cultivar (C)	Sowing Date (SD)			Average (C)
	30 April	7 May	21 May	
		2009		
Charlize	73.67	63.12	57.68	64.82
Jaquar	78.35	70.77	71.41	73.51
Python	55.59	49.50	54.40	53.16
South Wester	76.84	74.43	47.77	66.35
Average (SD)	71.11	64.46	57.82	
$LSD_{T(0.05)}$	**C = ns**	**SD = ns**	**C x SD = ns**	
		2010		
	11 May	25 May	8 June	
Charlize	70.02	67.46	45.86	61.11
Jaquar	70.59	65.90	54.27	63.59
Python	74.12	51.85	50.78	58.92
Ceres Gold	71.17	52.46	45.94	56.52
Average (SD)	71.48	59.42	49.21	
$LSD_{T(0.05)}$	**C = ns**	**SD = 11.60**	**C x SD = ns**	

Table 4.7: Influence of sowing date on bulb yield (t ha^{-1}) of different onion cultivars during 2009 and 2010

Cultivar (C)	Sowing Date (SD)			Average (C)
	30 April	7 May	21 May	
		2009		
Charlize	30.76	26.37	24.09	27.07
Jaquar	32.73	29.56	29.83	30.71
Python	23.22	20.68	22.72	22.21
South Wester	32.10	31.09	19.95	22.71
Average (SD)	29.70	26.93	24.15	
$LSD_{T(0.05)}$	**C = ns**	**SD = ns**	**C x SD = ns**	
		2010		
	11 May	25 May	8 June	
Charlize	40.13	38.65	26.28	35.02
Jaquar	40.45	37.76	31.10	36.44
Python	42.47	29.71	29.10	33.76
Ceres Gold	40.79	30.06	26.32	32.39
Average (SD)	40.96	34.05	28.20	
$LSD_{T(0.05)}$	**C = ns**	**SD = 6.64**	**C x SD = ns**	

The average fresh mass per onion bulb in 2009 (64.46 g) and 2010 (60.04 g) did not differ much from each other but the average yield between 2009 (25.68 t ha^{-1}) and 2010 (34.40 t ha^{-1}) differed by nearly 10 t ha^{-1}. This may be attributed to the fact that two different plant populations were used during the two seasons, with approximately 190 000 more plants ha^{-1} being planted in 2010 (Table 3.2). The best sowing date for all the cultivars when considering yield parameters was late April to early May. 'Charlize', (short day cultivar), yielded 35.02 t ha^{-1} in 2010 (606 061 plants ha^{-1}) which was 7.95 t ha^{-1} more than what was harvested in 2009 where a different plant population was used (416 667 plants ha^{-1}). When comparing the four intermediate day onion cultivars, 'Jaquar' bulbs were the heaviest and yielded the highest in both seasons. The lowest yield in 2009 was obtained from 'Python' (22.21 t ha^{-1}) and in 2010 from 'Ceres Gold' (32.39 t ha^{-1}). Cheema *et al.* (2003) reported that onion cultivars vary in terms of yield since they differ in their genetic composition.

As indicated in Table 4.1, 'South Wester' bulbs were all harvested on the same date, irrespective of sowing date in 2009. This was also true for 'Ceres Gold' (mid-intermediate day onion cultivar) in 2010 (Table 4.1). The two early intermediate day onion cultivars were harvested two months earlier (November) than the mid-intermediate day onion cultivars (January). With the two early-intermediate day onion cultivars ('Jaquar' and 'Python') a trend was observed that the bulbs of plants sown on 7 May were harvested when they had reached the same growth duration with those sown early (30 April). This may have an important effect on the price obtained on the fresh produce markets. 'Charlize' (short day cultivar) responded differently during the two seasons (Table 4.1). 'Charlize' bulbs were harvested earlier in 2010 than in 2009. This may be due to higher average maximum day temperatures (Table 3.1) experienced during 2010 than in 2009 resulting in growing degree days of 600 being reached earlier. When considering the number of days from sowing to harvesting (Table 4.1) a trend can be noticed that late sown onions have a shorter growth period, resulting in lower yields.

Different cultivars perform differently even if they are sown on the same date (Mondal *et al.*, 1986) and is attributed to their different genetic makeup. Leilah *et al.* (2003) also reported that the yield of different cultivars differ due to their different genetic composition. However, the current study indicated that bulb fresh mass and yield of different cultivars did not differ significantly from each other (Table 4.6 and 4.7).

The results on yield indicated that the best sowing date for all cultivars studied for the Bloemfontein area are from the end of April up to the end of May. These is within the range of sowing times (mid-April for short day and end April to mid-May for intermediate day cultivars) suggested by Comrie (1997b).

4.2.2.2 Bulb diameter (size)

Bulb sizes of onion cultivars differed significantly from each other in 2009 (Table 4.8). 'Python' bulbs (72.20 mm) were significantly smaller than 'South Wester' (82.51 mm) and 'Jaguar' (80.50 mm) bulbs. 'Charlize' bulbs (79.78 mm) did not differ significantly in size from any of the other cultivars. Sowing date did not significantly affected bulb size (Table 4.8).

Table 4.8: Influence of sowing date on bulb diameter (mm) of different onion cultivars during 2009 and 2010

Cultivar (C)	Sowing Date (SD)			Average
	30 April	7 May	21 May	(C)
		2009		
Charlize	80.83	81.34	77.16	79.78
Jaquar	84.77	74.35	82.38	80.50
Python	67.59	77.29	71.72	72.20
South Wester	82.43	81.05	84.05	82.51
Average (SD)	78.91	78.51	78.83	
$LSD_{T(0.05)}$	**C = 8.14**	**SD = ns**	**C x SD = ns**	
		2010		
	11 May	**25 May**	**8 June**	
Charlize	52.59	57.01	51.37	53.66
Jaquar	56.21	63.95	52.76	57.64
Python	56.85	53.41	52.57	54.28
Ceres Gold	63.79	57.94	58.44	60.06
Average (SD)	57.36	58.08	53.79	
$LSD_{T(0.05)}$	**C = 5.22**	**SD = 4.09**	**C x SD = ns**	

Bulb diameter was significantly influenced by both cultivar and sowing date during 2010 (Table 4.8). 'Ceres Gold' bulbs (60.06 mm) were significantly larger than those of 'Charlize' (53.66 mm) and 'Python' (54.28 mm) bulbs. No significant difference occurred in bulb size between 'Jaquar' and 'Ceres Gold'. Bulb diameter of onions sown on the 25 May (58.08 mm) was significantly greater than that of bulbs from plants sown late on 8 June (53.79 mm).

Bulb size ranged between 72.20 and 82.51 mm in 2009 and from 53.66 to 60.06 mm in 2010. According to the local grading system used on the fresh produce markets all the bulbs from 2009 graded as large (70-89 mm), while in 2010 they were medium bulbs (40-69 mm) (Joubert & Van der Klashorst, 1997). According to Kanton *et al.* (2002) medium bulbs are more desirable than large bulbs by the consumers and higher prices are consequently obtained on the fresh produce markets for medium bulbs. The difference in bulb size between the two seasons may be attributed to the different plant populations used between the two seasons (416 667 plants m^{-2} in 2009 and 606 061 plants m^{-2} in 2010). Khan *et al.* (2002), Rahman *et al.* (2002), Khan *et al.* (2003), Shock *et al.* (2004) and Russo (2008) also reported that bulb diameter corresponded with plant population.

Results indicated that none of the cultivars produced medium or small bulbs where a less dense plant population was used (416 667 plants m^{-2}) during 2009. However, during 2010, when a denser plant population (606 061 plants m^{-2}) was used, almost all bulbs produced were of medium size.

4.2.2.3 Neck diameter

Both cultivar and sowing date affected neck diameter of onion bulbs significantly during 2009 (Table 4.9). 'South Wester' plants produced bulbs with significantly thicker necks (22.55 mm) than plants from all the other cultivars. The thinnest necks (15.20 mm), also significantly thinner than the bulb necks from 'Python' plants, were produced by plants of the cultivar Charlize.

Table 4.9: Influence of sowing date on neck diameter (mm) of different onion cultivars during 2009 and 2010

Cultivar (C)	**Sowing Date (SD)**			**Average**
	30 April	**7 May**	**21 May**	**(C)**
		2009		
Charlize	16.71	15.47	13.43	15.20
Jaquar	20.51	17.45	15.05	17.67
Python	19.26	16.12	21.03	18.80
South Wester	23.48	21.41	22.76	22.55
Average (SD)	19.99	17.61	18.07	
$LSD_{T(0.05)}$	**C = 3.01**	**SD = 2.36**	**C x SD = ns**	
		2010		
	11 May	**25 May**	**8 June**	
Charlize	7.46	8.63	7.42	7.84
Jaquar	9.10	9.95	8.23	9.09
Python	13.17	13.83	14.43	13.81
Ceres Gold	19.18	19.22	18.49	18.96
Average (SD)	12.23	12.91	12.14	
$LSD_{T(0.05)}$	**C = 1.12**	**SD = ns**	**C x SD = ns**	

Plants sown on 30 April produced bulbs with significantly thicker necks compared to those sown on 7 May. However, the necks of onions from plants that were sown on 21 May did not differ significantly from those at the other two sowing dates. In 2010, neck diameter of onion plants from different cultivars differed significantly from each other (Table 4.9). 'Ceres Gold' plants produced significantly thicker necks (18.96 mm) than those of 'Python'

(13.81 mm), 'Jaquar' (9.09 mm) and 'Charlize' (7.84 mm). Sowing date did not affect neck diameter at all during this year.

Onion bulbs with thinner necks have a better storage life than bulbs with thicker necks (Mohanty & Prusti, 2001; Jilani & Ghaffoor, 2003). Different onion cultivars often differ with regard to neck size (Jilani & Ghaffoor, 2003). This was also observed in the present study in the two consecutive years (Table 4.9). In both seasons plants of the mid-intermediate day cultivars ('South Wester' and 'Ceres Gold') had thicker necks, followed by those of the two early-intermediate day cultivars ('Python' and 'Jaquar'), while plants from 'Charlize' (short day cultivar) had the thinnest necks.

The overall bulb neck diameter was much smaller in 2010 than in 2009. Bulbs with thinner necks originated from smaller plants due to a more dense plant population in 2010 than in 2009. Dawar *et al.* (2005) also reported that bulbs with thinner necks were obtained from more dense plant populations in Peshawar. The thickest onion bulb neck diameter (2.09 cm) was recorded from a plant population of 40 plants m^{-2} and it steadily decreased to 1.93 cm and 1.83 cm as plant population increased from 60 to 80 plants m^{-2}, respectively. Sowing date did not have such a pronounced affect on bulb neck diameter, but the thinnest necks (17.61 cm) were obtained with the mid sowing date of 7 May in 2009 and the late sowing date of 8 June in 2010 (12.14 cm). Jilani (2004), reported that the thickest onion bulb necks were obtained with early plantings (27 October) compared to late plantings (26 December) in Pakistan. Attainment of a thinner neck with later planting is associated with small plants caused by earlier bulb initiation for late planted plants than for earlier plantings.

4.2.2.4 Bulb firmness

Different sowing dates did not significantly influence onion bulb firmness but bulbs from different cultivars differed significantly in their firmness in both seasons (Table 4.10). In 2009, 'South Wester' bulbs were significantly softer (87.02 mm) than all the other cultivars. 'Python' bulbs were significantly firmer than all the other cultivars. During 2010, bulbs of 'Charlize' (70.99 mm) were significantly firmer than those of 'Jaquar' (83.88 mm) but were not significantly firmer than of those bulbs of 'Python' (74.70 mm) and 'Ceres Gold' (77.84 mm). Although sowing date did not significantly affect bulb firmness, firmer bulbs were obtained from onion plants sown on 8 June (68.85 mm) followed by 30 April (73.41 mm) and then 7 May (74.56 mm) in 2009. In 2010 the firmest bulbs were harvested from plants sown on the 21 May (73.22 mm) followed by 25 May (78.19 mm) and then 11 May (79.15 mm). Onion cultivars differ with regards to bulb firmness due to their genetic makeup (Lancaster *et al.*, 2001; Chope *et al.*, 2006; Larsen *et al.*, 2009). This was confirmed by the current study as the firmness of the different onion cultivars bulbs differed from each other during both seasons (Table 4.10).

Table 4.10: Influence of sowing date on bulb firmness (mm) of different onion cultivars during 2009 and 2010

Cultivar (C)	Sowing Date (SD)			Average (C)
	30 April	7 May	21 May	
		2009		
Charlize	70.08	70.95	64.18	68.40
Jaquar	79.89	72.47	69.08	73.81
Python	56.76	66.22	56.58	59.85
South Wester	86.90	88.61	85.55	87.02
Average (SD)	73.41	74.56	68.85	
$LSD_{T(0.05)}$	**C = 8.26**	**SD = ns**	**C x SD = ns**	
		2010		
	11 May	**25 May**	**8 June**	
Charlize	77.57	74.10	61.29	70.99
Jaquar	87.13	86.96	77.56	83.88
Python	74.70	73.02	76.38	74.70
Ceres Gold	77.18	78.68	77.66	77.84
Average (SD)	79.15	78.19	73.22	
$LSD_{T(0.05)}$	**C = 7.87**	**SD = ns**	**C x SD = ns**	

No literature cited associated bulb firmness with sowing date. Results of the current study indicated that later sown onions produced firmer bulbs, although this was not significant. This may be due to more rain occurring during bulb formation of the later sown onions than the earlier sown onions. Chung (1989) in Australia reported that bulbs receiving more water tend to be firmer. Softer bulbs were harvested from dryland than irrigated planting treatments. On the other hand, Gubb & MacTavish (2002) reported that wet condition towards or during harvesting is a disadvantage as it prolongs the drying of bulbs and promotes high percentages of rotting during storage.

4.2.2.5 Bolting

Bolting percentages of onion were not statistically analyzed. In 2009, 'South Wester' and 'Python' bolted whereas 'Charlize' and 'Jaquar' did not show any sign of bolting. No bolting occurred during 2010.

With an early sowing of 'South Wester' (30 April), 30.30% of the plants bolted and as sowing date was delayed to 7 or 21 May, the percentage of bolters decreased to 24.24 and 18.18%, respectively. Only 12.12% of 'Python' plants bolted when sown on 30 April and none of the plants bolted when sown later.

First incidences of bolting were noted on 'South Wester' and for 'Python' during early August in 2009 on plants sown on 30 April. Results indicate that bolting of these cultivars was clearly influenced by temperature and cultivar. The minimum temperatures at the start of bolting ranged from -2.3°C to 11.9°C. 'Python' and 'South Wester' sown on 30 April had reached the sensitive stage for bulbing (thermal time of 600 degree days), but the occurrence of low temperatures may have been the reason for bolting taking place. However, 'South Wester' sown on 7 May and 21 May had not yet reached the thermal time of 600 degree days (Table 4.1) when day length was sufficient for bulbing and started to bolt, thus indicating that 'South Wester' may be more susceptible to bolting (van den Berg *et al.*, 1997) than other cultivars.

4.2.2.6 Bulb shape

Hasegawa *et al.* (2001) and Jilani & Ghaffoor (2003) indicated that every cultivar has a typical bulb which varies from flattened, globular and spherical shape. Bulb shape in this study was visually determined using the norms of Boyhan & Kelley (2008) (Section 3.4.2.5). The results showed that sowing date did not affect bulb shape in any of the seasons. 'Charlize' produced globular bulbs, 'South Wester' round bulbs, 'Python' and 'Jaquar' top shaped bulbs which were cultivar authentic. Grant & Carter (1994) stated that agronomic practices such as sowing date and plant population may affect bulb shape. They reported that if plant population increased from 50 to 100 plants m^{-2} and if sowing date was delayed from June to September, the bulb shape index changed (Section 2.4.4) from 1.02 to 1.06, meaning that the bulbs getting more oblate in shape. This trend was not obtained in this study, and this may be due to the much lower plant populations (41 and 61 plants m^{-2} during 2009 and 2010, respectively) used.

From the current results, it can be noted that bulb shape was affected by the cultivar and not the sowing date. Onions sown early produced large bulbs, thickest necks and high bolting percentage. When sown late, bulbs tended to be more firm. Intermediate day cultivars ('South Wester', 'Ceres Gold' and 'Python') produced large firm bulbs with large necks. Moreover, 'South Wester' and 'Python' were the only cultivars that had bolted. The shape of onion bulbs was influenced by the type of cultivar rather than sowing date.

4.3 SUMMARY AND CONCLUSIONS

Two field experiments on the response of onion cultivars to different sowing dates were conducted in 2009 and 2010. 'Python' plants developed more vigorously (plant height and leaf number) than of all the other cultivars during both seasons. Sowing date did not have a significant influence on growth of onions in 2009 and it was only during 2010 that a delayed sowing date caused onion plants to be shorter.

Neither bulb fresh mass nor yield differed significantly between cultivar, although 'Jaquar' tended to produce the heaviest bulbs and the highest yield. Sowing from the end of April to the middle of May made no significant difference to bulb fresh mass and yield, but with a delayed sowing date (later than end May) both parameters decreased significantly.

Significant differences in bulb quality characteristics were noted between cultivars. The mid-intermediate day cultivars ('South Wester' and 'Ceres Gold') produced the largest bulbs (82.51 and 60.06 mm, respectively) with the thickest necks (22.55 and 18.96 mm, respectively) during both seasons. Although 'Jaquar' also produced large bulbs (80.50 in 2009 and 57.64 mm in 2010), it had thinner necks (17.67 mm in 2009 and 9.09 mm in 2010). During 2010, medium bulbs (58.08 mm) with thin necks (12.91 mm) were obtained when sowing was done towards the end of May. Bulb firmness and shape were not significantly influenced by sowing date, however, 'Python' produced the firmest bulbs. 'South Wester' and 'Python' were susceptible to bolting when sowing was done early (30 April or 7 May).

From the data, it is clear that onion cultivars differ from each other with respect to growth, yield and quality. Sowing date did not have a significant effect on all of the parameters measured, but a reduction in growth and yield of onions was observed when sowing was delayed to the end of May. Cultivars tested can be sown from early to late May in the Bloemfontein area, although the best results are obtained from sowing in middle May.

REFERENCES

AGIC, R., POPSIMONOVA, G., JANKULOVSKI, D. & MARTINOVSKI, G., 2007. Winter onion susceptibility to premature bolting depending on the variety and the sowing date. *Acta Hort.* 729, 271-276.

ANSARI, N.A., 2007. Effect of density, cultivars and sowing date on onion sets production. *Asian J. Plant Sci.* 6, 1147-1150.

BOYHAN, G. & KELLEY, W.T., 2008. Variety selection and characteristics. *In:* G.E. Boyhan & W.T. Kelley (eds.). Onion production guide. Cooperative Extension. The University of Georgia, Georgia, United States of America.

BREWSTER, J.L., 1977. The physiology of the onion. *Hort. Abst.* 47, 17-23.

BREWSTER, J.L., 1994. Onions and other vegetable alliums. 1st edn., CAB International, Wallingford, United Kingdom.

BREWSTER, J.L., 2008. Onions and other vegetable alliums. 2nd edn., CAB International, Wallingford, United Kingdom.

CHEEMA, K.L., SAEED, A. & HABIB, M., 2003. Effect of sowing date on set size in various cultivars of onion (*Allium cepa* L.). *Int. J. Agric. Biol.* 5, 185-187.

CHOPE, G.A., TERRY, L.A. & WHITE, P.J., 2006. Effect of controlled atmosphere storage on abscisic acid concentration and other biochemical attributes of onion bulbs. *Postharv. Biol. Technol.* 39, 233-242.

CHUNG, B., 1989. Irrigation and bulb onion quality. *Acta Hort.* 247, 233-237.

COMRIE, A.G., 1997a. Climatic and soil requirements for onions. Onions B.1. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

COMRIE, A.G., 1997b. How to grow onions. Onions E.1. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

DAWAR, N.M., WAZIR, F.K., DAWAR, M. & DAWAR, S.H., 2005. Effect of planting density on the performance of three varieties of onion under the agro-climatic conditions of Peshawar. *Sarhad J. Agric.* 21, 545-550.

GRANT, D.G. & CARTER, B.V., 1994. The influence of cultural factors on the bulb of the onion (*Allium cepa* L.) cultivar 'Pukekohe Longkeeper'. *Acta Hort.* 433, 527-532.

GUBB, I.R. & MACTAVISH, H.S., 2002. Onion pre and postharvest considerations. *In*: H.D. Rabinowitch and L. Currah (eds.). Allium crop science: recent advances. CAB International, Wallingford, United Kingdom.

HASEGAWA, A., YABUKI, H., NABEURA, T., FUKUI, H. & IWATA, T., 2001. Evaluation of bulb shape and fresh-weight of different onion cultivars. *Tech. Bull. Agric. Kagawa Univ.* 53, 71-77.

HYGROTECH, 2009a. Onion variety profiles: Short day length. Hygrotech Sustainable Solutions. www.hygrotech.com (Accessed 10/05/09).

HYGROTECH, 2009b. Onion variety profiles: Intermediate day length. Hygrotech Sustainable Solutions. www.hygrotech.com (Accessed 10/05/09).

JILANI, M.S., 2004. Studies on the management strategies for bulb and seed production of different cultivars of onion (*Allium cepa* L.). M.Sc. dissertation, North West Frotier Province of Pakistan. Agriculture University, Peshawar, Pakistan.

JILANI, M.S. & GHAFFOOR, A., 2003. Screening of local varieties of onion for bulb formation. *Int. J. Agric. Biol.* 5, 129-133.

JOUBERT, T.G. LA G. & VAN DER KLASHORST, E., 1997. The marketing, grading and export of onions. Onions J.1. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

KANTON, A.L., ABBEY, L., HILLA, R.G., TABIL, M.A. & JAN, N.D., 2002. Density affects plant development and yield of bulb onion (*Allium cepa* L.) in Northern Ghana. *J. Veg. Crop Prod.* 8, 15-25.

KHAN, H., IQBAL, M., GHAFFOOR, A. & WASEEM, K., 2002. Effect of various plant spacing and different nitrogen levels on the growth and yield of onion (*Allium cepa* L.). *J. Biol. Sci.* 2, 545-547.

KHAN, M.A., HASAN, M.K., MIAH, M.A.J., ALAM, M.M. & MASUM, A.S.M.H., 2003. Effect of plant spacing on the growth and yield of different varieties of onion. *Pakistan J. Biol. Sci.* 6, 1582-1585.

KHOKHAR, K.M., HADLEY, P. & PEARSON, S., 2007. Effect of cold temperature durations of onion sets in store on the incidence of bolting, bulbing and seed yield. *Sci. Hortic.* 112, 16-22.

LANCASTER, J.E., FARRANT, J. & SHAW, M., BYCROFT, B. & BRASH, D., 2001. Does sulphur supply to the bulb affect storage of onions? *Acta Hort.* 555, 111-115.

LANCASTER, J.E., TRIGGS, C.M., DE RUITER, J.M. & GANDAR, P.W., 1996. Bulbing in onions: photoperiod and temperature requirements and prediction of bulb size and maturity. *Ann. Bot.* 78, 423-430.

LARSEN, T., SAXENA, A. & CRAMER, C.S., 2009. Relatedness of bulb firmness to other attributes of New Mexico onion entries. *Int. J. Veg. Sci.* 15, 206-217.

LEILAH, A.A., EL-KALLA, S.A., MOSTAFA, A.K. & AFIFI, H.M.A., 2003. Performance of some local Egyptian onion strains under different planting dates. *Sci. J. King Faisal Univ.* 4, 119-136.

MOHANTY, B.K. & PRUSTI, A.M., 2001. Performance of common onion varieties in Kharif seasons. *J. Trop. Agric.* 39, 21-23.

MONDAL, M.F., BREWSTER, J.L., MORRIS, G.E.L. & BUTLER, H.A., 1986. Bulb development in onion (*Allium cepa* L.). I. Effects of plant density and sowing date in field conditions. *Ann. Bot.* 58, 187-195.

MSUYA, D.G., REUBEN, S.O.W.M., MBILINYI, L.B., MAERERE, A.P., MSOGOYA, T., MULUNGU, L.S. & MISANGU, R.N., 2005. Evaluation of field performance and storage of some tropical short-day onion (*Allium cepa* L.) cultivars. *W. Afr. J. Ecol.* 8, 10-18.

OKPORIE, E.O. & EKPE, I.I., 2008. Effect of photoperiod on the growth and bulbing of tropical onion (*Allium cepa* L.) varieties. *W. J. Agric. Sci.* 4, 36-39.

QUADIR, M.A. & BOULTON, A., 2005. Yield and maturity of new released red onion cultivars in New South Wales. *Acta Hort.* 694, 117-119.

RAHMAN, M.A., SAHA, R.S., SALAM, M.A., MASUM, A.S.M.H. & CHOWDHURY, S.S., 2002. Correlation and path coefficient analysis in onion (*Allium cepa* L.). *J. Biol. Sci.* 2, 531-532.

RICHWINE, P.A., 1990. Effect of fall planting date on bulb yield of 'sweet winter' onion in the rolling plains of Texas. *HortScience* 25, 981.

RUSSO, V.M., 2008. Plant density and nitrogen fertilizer rate on yield and nutrient content of onion development from greenhouse-grown transplants. *HortScience* 42, 1759-1764.

SHOCK, C.C., FEIBERT, E.B.G. & SAUNDERS, L.D., 2004. Plant population and nitrogen fertilization for subsurface drip irrigated onion. *HortScience* 39, 1722-1727.

SMITH, B., 2006. The farming handbook. University of Kwazulu-Natal Press, Pietermaritzburg, South Africa.

SMITTLE, D., 1993. Onion production in the tropics. Assigment: ST-115, Chemonic International, Washington, United States of America.

STEER, B.T., 1980. The bulbing response to day length and temperature of some Australasian cultivars of onion (*Allium cepa* L.). *Aust. J. Agric. Res.* 31, 511-518.

SULLIVAN, D.M., BROWN, B.D., SHOCK, C.C., HORNECK, D.A., STEVENS, R.G., PELTER, G.Q. & FEIBERT, E.B.G., 2001. Nutrient management for onions in the Pacific North West. A Pacific Extension Publication No. 546. Oregon State University. Pacific North West, United States of America.

VAN DEN BERG, A.A., DE WET, H. & COERTZE, A.F., 1997. Onion cultivars. Onions C.1. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

WICKRAMASINGHE, U.L., WRIGHT, C.J. & CURRAH, L., 2000. Bulbing responses of two cultivars of red tropical onions to photoperiod, light integral and temperature under controlled growth conditions. *J. Hortic. Sci. Biotechnol.* 75, 304-311.

WURR, D.C.E., HAND, D.W., EDMONDSON, R.N., FELLOWS, J.R., HANNAH, M.A. & CRIBB, D.M., 1998. Climate change: a response surface study of the effects of CO_2 and temperature on the growth of beetroot, carrots and onions. *J. Agr. Sci.* 131, 125-135.

CHAPTER 5

RESPONSE OF ONION (*Allium cepa* L.) TO SOWING DATE AND PLANT POPULATION

5.1 INTRODUCTION

Onion (*Allium cepa* L.) growth is greatly influenced by environmental factors (photoperiod and temperature) and agronomic practices. Cultivar selection, sowing date and plant population are among the critical agricultural practices influencing onion production. Plant population is described as the number of plants per square meter (plants m^{-2}) or per hectare (plants ha^{-1}) and has been reported to influence growth, quality and yield of onion bulbs (Hatridge-Esh & Bennett, 1980; Brewster, 1994; Dellacecca & Lovato, 2000).

According to Adjei-Twum (1980) cited by Ibrahim (2010) the primary objective of any producer is to attain high yields and for onions the final yield depends on the amount of vegetative growth before bulb initiation. Two major factors influencing vegetative growth are sowing date and plant population. Early sowing of onions results in more vegetative growth (leaf length and number of leaves) (Brewster, 1994; Mulungu *et al.,* 1998), which ultimately reflects in the leaf area index (LAI) (Brewster, 1994). Leaf area index is made up of the amount of leaves per plant on a given unit area (Amanullah *et al.*, 2007). Both early sowing and an increase in plant population will increase the LAI (Mondal *et al.*, 1986). Leaf area index influences the amount of light absorbed by the leaves and this is influenced by an increase in plant population (Gardner *et al.*, 1985). Healthy leaves are needed by plants for interception of sunlight for photosynthesis and for the conversion of carbohydrates to sucrose, which will be transported to the harvestable organs. Jilani (2004) and Jilani *et al.* (2009) reported that thinly populated plants (20 plants m^{-2}) produce a greater number of longer leaves than more densely populated plants (40 plants m^{-2}). As plant population increased, onion bulb yield also increased as results of a higher percentage light intercepted by the leaf canopy (Brewster, 2008).

The yield of late sown plants will be lower as a result of switching from leaf blade production to bulb initiation while the LAI and light interception are still low compared to earlier sown plants (Pakyürek *et al.*, 1994; Brewster, 2008). Therefore, sufficient time is needed for production of leaves before bulb initiation. As plant population increases, more sunlight will be absorbed, resulting in more vegetative growth before bulbing with a concomitant increase in yield. However, research on different plant populations indicated that a yield of between 31 and 59 t ha^{-1} can be expected with a plant population ranging between 80 and 100 plants m^{-2}. However, with a plant population lower than 60 plants m^{-2} or more than 100 plants m^{-2} onion yield will decrease (Dellacecca & Lovato, 2000; Rumpel & Felczyński, 2000; Kanton *et al.*, 2002).

Bulb size is an important quality characteristic and different markets require different bulb sizes. The fresh produce markets in South Africa prefer medium bulbs (40-69 cm) (Comrie, 1997) and for exporting to Europe, bulbs ranging between 40 and 60 mm are required (Lai *et al.*, 1994; Rumpel & Felczyński, 2000; Bosch Serra & Currah, 2002). Comsumers in the United States of America (USA) prefer large (>76 mm) (Leskovar & Vavrina, 1999) and extra-large bulbs (>108 mm) (Shock *et al.*, 2004). The processing industry (canning, oil extraction, freezing and dehydration), can use bulbs ranging from extra small (10-34 mm) to extra-large (>90 mm), but no split bulbs are excepted (McGeary, 1985; Shock *et al.*, 2005). According to Brewster (1994), a plant population between 50-100 plants m^{-2} will produce bulbs that are between 50-70 mm in diameter, which are preferred in most markets, while at a plant population of 25-50 plants m^{-2} large bulbs (>70 mm), which are suitable for the processing industry, will be produced.

Although earlier sowing produces larger plants, these start to form bulbs at a shorter day length than smaller plants. This increases the possibility for larger plants to enter the sensitive bulb initiation stage when temperatures are still low (Khokhar *et al.*, 2007), thus promoting bolting (Richwine, 1990). To avoid or minimize bolting, sowing should be arranged in such a way that the size at which plants are susceptible to bolting is avoided before bulbing.

Split bulbs are one of the quality parameters that result in downgrading of onion bulbs. These are common in large bulbs, normally resulting from larger plants, and this is also associated with a lower plant population. In Bangladesh, Khan *et al.* (2003) reported that at a low plant population (48 plants m^{-2}), 24.34% of the total bulb yield split whereas only 14.38% of bulbs split from more dense plant population of 163 plants m^{-2}. Larger plants easily form split bulbs because of the development of more leaf bases further away from the apical meristem and eventually producing split bulbs (Rabinowitch, 1979).

Plant population also influences the shape of onion bulbs. Bulb shape is also among the quality characteristics determining the marketability of onions and round bulbs are preferred in South Africa (Eksteen *et al.*, 1997). An increase in plant population leads to elongated bulbs (Hygrotech, 2010).

Plant population also affects the time of bulb maturity (Weerasinghe & Fordham, 1994; Rumpel & Felczyński, 2000; Tarpaga *et al.*, 2011). When bulbs reach maturity, production of leaves cease, implying that bulb yield and quality attained depends on the leaves already produced (Ibrahim, 2010). Bulbs of densely populated plants mature earlier than those of less populated plants (Mondal *et al.*, 1986; Weerasinghe & Fordham, 1994). Brewster (1990) reported a 20 day delay in maturity with a plant population of 25 plants m^{-2} compared to 100 plants m^{-2}.

The current study was aimed at assessing the effect of sowing date and plant population on the growth, yield and quality characteristics of onion cv. Jaquar under field conditions at Bloemfontein in the Central Free State.

5.2 RESULTS AND DISCUSSION

5.2.1 Growth parameters

Plant height and leaf number were recorded to determine the growth of onion plants as influenced by sowing date and plant population. Measurements were taken every three weeks from emergence, and are presented in both table and graph forms. Tables were used to indicate the $LSD_{T(0.05)}$ values for each week of measurement, while figures illustrate the growth response over the trial period.

5.2.1.1 Onion growth

The growth period of the onion cv. Jaquar used in this trial is presented in Table 5.1. The expected bulb initiation date according to the minimum day length requirement and also the date when the thermal time of 600 degree days was reached is indicated in Table 5.1. Thermal time was calculated from the emergence date using the equation discussed in Chapter 2, Section 2.5.1.4.

Table 5.1: Summary of the growth period of 'Jaquar' (early-intermediate day cultivar) as influenced by sowing date and plant population during 2010

Plant Population (plants m^{-2})	Sowing date	Emergence date	Sowing to emergence (days)	Thermal time (600 degree days)	Earliest expected bulb initiation date	Emergence to expected bulb initiation (days)	Average maximum day temperature from emergence to expected bulb initiation (°C)	Final plant height (cm)	Final leaf number	Sowing to harvesting (days)	Harvesting date	Yield (t ha^{-1})	Grading (%)				
													XS	S	M	L	XL
	11 May	24 May	13	31 Aug		118	20.1	50.33	8.00	181	8 Nov	37.45	33.3	27.3	39.4	0.0	0.0
95	25 May	14 June	20	10 Sept	19 Sept	97	20.5	41.48	7.67	167	8 Nov	43.24	30.3	21.2	48.5	0.0	0.0
	8 June	6 July	28	17 Sept		76	21.6	47.39	7.00	153	8 Nov	27.31	15.2	21.2	63.6	0.0	0.0
	11 May	24 May	13	31 Aug		118	20.1	52.55	7.67	181	8 Nov	36.12	9.1	18.2	72.7	0.0	0.0
83	25 May	14 June	20	10 Sept	19 Sept	97	20.5	45.33	7.33	167	8 Nov	44.20	9.1	33.3	54.5	3.1	0.0
	8 June	06 July	28	17 Sept		76	21.6	50.00	7.67	153	8 Nov	29.82	6.1	21.2	72.7	0.0	0.0
	11 May	24 May	13	31 Aug		118	20.1	53.46	7.33	181	8 Nov	41.15	0.0	6.1	84.8	9.1	0.0
74	25 May	14 June	20	10 Sept	19 Sept	97	20.5	50.03	7.67	167	8 Nov	41.17	9.1	9.1	81.8	0.0	0.0
	8 June	6 July	28	17 Sept		76	21.6	49.91	7.67	153	8 Nov	37.65	0.0	0.0	93.9	6.1	0.0
	11 May	24 May	13	31 Aug		118	20.1	54.24	7.33	181	8 Nov	45.38	0.0	0.0	42.4	57.6	0.0
67	25 May	14 June	20	10 Sept	19 Sept	97	20.5	52.42	7.00	167	8 Nov	33.26	0.0	0.0	75.8	24.2	0.0
	8 June	6 July	28	17 Sept		76	21.6	49.97	7.33	160	15 Nov	32.88	0.0	3.0	75.8	21.2	0.0
	11 May	24 May	13	31 Aug		118	20.1	57.91	7.33	181	8 Nov	40.90	0.0	0.0	51.5	48.5	0.0
61	25 May	14 June	20	10 Sept	19 Sept	97	20.5	55.54	7.33	167	8 Nov	36.86	0.0	3.0	75.8	21.2	0.0
	8 June	6 July	28	17 Sept		76	21.6	51.76	7.33	160	15 Nov	39.32	0.0	0.0	78.8	21.2	0.0

5.2.1.2 Plant height

The interaction between plant population and sowing date did not significantly affect plant height over the entire period (Table 5.2). Plant height was not affected by plant population during the first 12 weeks after emergence, but later in the season, from week 15 after emergence onwards, it was affected significantly. Sowing date, however, significantly affected onion plant height over all measuring times.

Table 5.2: Influence of sowing date and plant population on plant height (cm) from 3 to 18 weeks after emergence

Plant population (PP) (plants m^{-2})	Sowing Date (SD)			Average (PP)
	11 May	25 May	8 June	
		3 weeks after emergence		
95	4.18	4.03	3.18	3.80
83	4.09	4.09	3.00	3.73
74	4.09	4.06	3.06	3.74
67	4.03	4.00	3.12	3.72
61	4.12	4.09	3.00	3.74
Average (SD)	**4.10**	**4.05**	**3.07**	
$LSD_{T(0.05)}$	**PP = ns**	**SD = 0.06**	**PP x SD = ns**	
		6 weeks after emergence		
95	8.15	5.57	6.88	6.87
83	7.91	6.48	7.12	7.17
74	7.76	5.94	6.97	6.89
67	7.94	6.70	6.97	7.20
61	8.18	6.09	6.82	7.03
Average (SD)	**7.99**	**6.16**	**6.95**	
$LSD_{T(0.05)}$	**PP = ns**	**SD = 0.54**	**PP x SD = ns**	
		9 weeks after emergence		
95	10.00	7.91	7.58	8.50
83	9.88	7.79	7.48	8.38
74	9.30	7.73	7.79	8.27
67	9.73	8.09	8.27	8.70
61	10.30	7.58	8.88	8.92
Average (SD)	**9.84**	**7.82**	**8.00**	
$LSD_{T(0.05)}$	**PP = ns**	**SD = 0.71**	**PP x SD = ns**	
		12 weeks after emergence		
95	14.91	15.57	12.46	14.31
83	14.00	14.94	11.85	13.60
74	15.21	14.97	12.82	14.33
67	15.27	14.40	12.29	13.99
61	17.58	14.42	14.09	15.36
Average (SD)	**15.39**	**14.86**	**12.70**	
$LSD_{T(0.05)}$	**PP = ns**	**SD = 1.26**	**PP x SD = ns**	
		15 weeks after emergence		
95	31.85	31.55	27.33	30.24
83	32.57	33.94	27.48	31.33
74	34.85	34.00	28.75	32.53
67	38.39	37.09	31.39	35.62
61	42.36	41.24	36.42	40.01
Average (SD)	**36.00**	**35.56**	**30.27**	
$LSD_{T(0.05)}$	**PP = 4.62**	**SD = 3.04**	**PP x SD = ns**	
		18 weeks after emergence		
95	50.33	41.48	47.39	46.40
83	52.55	45.33	50.00	49.29
74	53.46	50.03	49.91	51.13
67	54.24	52.42	49.97	52.21
61	57.91	55.54	51.76	55.07
Average (SD)	**53.70**	**48.96**	**49.81**	
$LSD_{T(0.05)}$	**PP = 4.62**	**SD = 3.04**	**PP x SD = ns**	

Although not always significant, plant height decreased as plant population increased during week 15 and 18 after emergence (Table 5.2). At week 15 after emergence, denser planted plants (74, 83 and 95 plants m^{-2}) were significantly shorter than the less denser (61 plants m^{-2}) planted plants. Plants planted at a density of 67 plants ha^{-1} were also significantly taller (35.62 cm) than plants from the denser planting of 95 plants m^{-2} (31.33 cm). At week 18 after emergence, plants planted at 95 plants m^{-2} were again significantly shorter (46.40 cm) than plants from the three lowest populated plantings of 61, 67 and 74 plants m^{-2} (55.07, 51.13 and 52.21 cm, respectively). However, plants planted at lower densities of 61, 67 or 74 plants m^{-2} did not significantly differ in height from each other.

Plants from the early sowing (11 May) were taller than later sown plants over the entire period of measuring, although this was not always significant. No clear trend was observed for onion plant height and sowing date over the first 18 weeks after emergence. Three weeks after emergence, onion plants sown on 11 May (53.70 cm) were significantly taller than plants sown later on 25 May (48.96 cm) or 8 June (49.81 cm). At week six after emergence, onion plants sown early (11 May) or late (8 June) were significantly taller (7.99 or 6.95 cm) than those plants sown 25 May (6.16 cm).

Significantly taller onion plants (9.84 cm) were obtained with an early sowing date (11 May) than with the two later sowing dates of 25 May (7.82 cm) or 8 June (8.00 cm), at week nine after emergence. At 12 and 15 weeks after emergence, onion plants sown late (8 June) were significantly shorter than those plants sown earlier (11 May or 25 May). Interestingly, at the final plant height (18 weeks after emergence) onion plants sown early (11 May) were significantly taller than plants sown on 25 May but not than those plants sown later (8 June).

5.2.1.3 Leaf number

It is clear from Table 5.3 that the interaction between plant population and sowing date did not significantly influence the number of leaves produced during the entire period, and this was also true for plant population. Sowing date only affected the number of leaves produced from week nine after emergence. Later sown plants (8 June) produced the most leaves (2.80), significantly more than early sown plants (11 May) with 2.33 leaves. However, 12 weeks after emergence the early sown plants (11 May) had significantly more leaves (4.00) than those plants sown later on 25 May (3.07) or 8 June (3.53). This trended however continued later in the growth season where early sown plants still tend to produce more leaves than the two later sowing dates, although not significantly more.

Table 5.3: Influence of plant population and sowing date on the number of leaves from 3 to 18 weeks after emergence

Plant Population (PP) (plants m^{-2})	Sowing Date (SD)			Average (PP)
	11 May	25 May	8 June	
		3 weeks after emergence		
95	1.33	1.33	1.33	1.33
83	1.00	1.67	1.33	1.33
74	1.67	1.33	1.67	1.56
67	1.00	1.67	1.67	1.45
61	1.33	1.33	1.67	1.44
Average (SD)	**1.27**	**1.47**	**1.53**	
$LSD_{T(0.05)}$	**PP = ns**	**SD = ns**	**PP x SD = ns**	
		6 weeks after emergence		
95	1.33	1.67	1.33	1.44
83	1.33	2.00	1.67	1.67
74	2.00	1.33	2.00	1.78
67	1.33	1.67	1.67	1.56
61	1.67	1.33	2.00	1.67
Average (SD)	**1.53**	**1.60**	**1.73**	
$LSD_{T(0.05)}$	**PP = ns**	**SD = ns**	**PP x SD = ns**	
		9 weeks after emergence		
95	2.67	2.67	3.00	2.78
83	2.00	3.00	2.33	2.44
74	2.33	2.67	2.67	2.56
67	2.33	2.67	3.00	2.67
61	2.33	2.33	3.00	2.55
Average (SD)	**2.33**	**2.67**	**2.80**	
$LSD_{T(0.05)}$	**PP = ns**	**SD = 0.44**	**PP x SD = ns**	
		12 weeks after emergence		
95	4.00	3.00	3.67	3.56
83	4.00	3.00	3.67	3.56
74	4.00	3.00	3.33	3.44
67	4.00	3.00	3.67	3.56
61	4.00	3.33	3.33	3.55
Average (SD)	**4.00**	**3.07**	**3.53**	
$LSD_{T(0.05)}$	**PP = ns**	**SD = 0.34**	**PP x SD = ns**	
		15 weeks after emergence		
95	7.33	6.33	6.00	6.55
83	6.00	6.00	6.33	6.11
74	7.00	6.33	6.33	6.55
67	7.00	6.33	6.33	6.55
61	6.33	6.33	5.67	6.11
Average (SD)	**6.73**	**6.26**	**6.13**	
$LSD_{T(0.05)}$	**PP = ns**	**SD = ns**	**PP x SD = ns**	
		18 weeks after emergence		
95	8.00	7.67	7.00	7.56
83	7.67	7.33	7.67	7.56
74	7.33	7.67	7.67	7.56
67	7.33	7.00	7.33	7.22
61	7.33	7.33	7.33	7.33
Average (SD)	**7.53**	**7.40**	**7.40**	
$LSD_{T(0.05)}$	**PP = ns**	**SD = ns**	**PP x SD = ns**	

The effect of plant population on the vegetative growth of onions has been studied in the past by numerous researchers. Jilani *et al.* (2009) reported taller plants from the less dense population (20 plants m^{-2}) than the denser populated planting (40 plants m^{-2}) and this was associated with competition between onion plants for available water and nutrients. However, Dawar *et al.* (2007) reported that as plant population increased from 40 to 80 plants m^{-2}, plant height (leaf length) also increased significantly from 47.79 to 52.51 cm. Plants compete for light and tend to grow taller to exploit light up to a maximum in denser plant populations. In the current study, however, plant height decreased and number of leaves increased as plant population increased.

The total number of onion leaves produced (18 weeks after emergence) was not significantly influenced by either plant population or sowing date and corresponded with the results of both Farooq-Ch *et al.* (1990) and Kanton *et al.* (2002). Farooq-Ch *et al.* (1990) stated that number of leaves produced by an onion plant is a genetic characteristic, and it is not influenced by plant population. However, other factors such as stress due to lack of nutrients or water during seedling growth, hail damage, damage from herbicides, pests and diseases can also affect the number of leaves produced by the onion plant (Brewster, 1990; Brewster, 1994; Bosch Serra & Currah, 2002; Khan *et al.*, 2002).

Results of the present study also showed that early sowing played a prominent role in final plant height. Early sown plants (11 May) were significantly taller than late sown plants. The reason for this may be due to a longer growth period of 118 days for early sown plants compared to 97 and 76 days for the late sown plants (Table 5.1). The average maximum temperatures during the different growth periods for the different sowing dates did not differ much from each other, and ranged between 20.1 and 21.6°C. These results are in agreement with those of Cramer (2003) who reported that early sown plants were taller than late sown plants due to a longer vegetative growth period.

The typical slow seedling growth phase of onions was also evident in this study on 'Jaquar' (Figure 5.1). Plant height and leaf number increased slowly during the first 12 weeks after emergence where after it sharply increased. The number of leaves showed a decline from 15 weeks after emergence and might be attributed to the fact that no more new leaves formed after bulb initiation (Jones & Mann, 1963).

A positive correlation between plant population and plant height for early sown (11 or 25 May) plants of 67 and 89% was observed compared to a weak correlation of only 22% for late sowing plants (8 June). Temperatures during this growth periods for the plants varied between 20.1 and 21.6°C (Table 5.1) and could not have had a major effect on the growth of the plants. A negative correlation between plant population and leaf number of 43 and 41% was observed indicating that leaf production is negatively influenced by plant population. Rahman *et al.* (2002) also reported a weak correlation of 8% between plant population (33-100 plants m^{-2}) and leaf number.

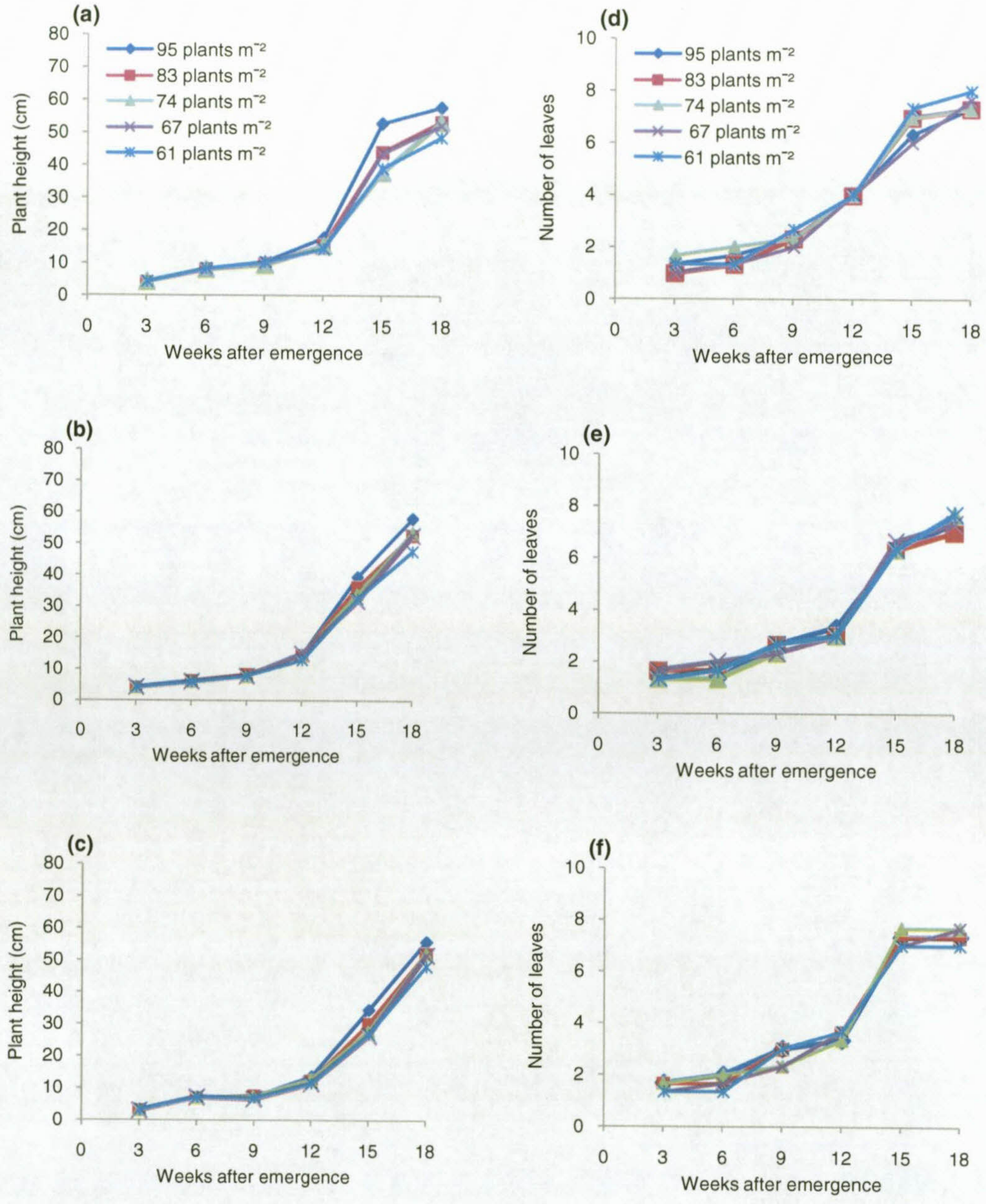


Figure 5.1: Plant height and number of leaves as influenced by seeds sown on different dates (a & d) 11 May, (b & e) 25 May and (c & f) 8 June, from 3 to 18 weeks after emergence

Considering plant height and number of leaves, the best sowing date for 'Jaquar' was 11 May at a plant population of between 61 and 74 plants m^{-2}

5.2.2 Bulb yield and quality parameters

5.2.2.1 Bulb fresh mass and yield

The interaction between plant population and sowing date did not significantly influence onion bulb fresh mass and yield. Plant population, however, significantly influenced bulb fresh mass but not the yield while sowing date significantly affected both (Table 5.4). Bulb fresh mass decreased as plant population increased, with the bulbs from plants at a density of 61 plants m^{-2} being significantly heavier than those of plants planted at 83 or 95 plants m^{-2}. Bulbs harvested from plants planted at the lowest population (61 plants m^{-2}) were 38.46 and 28.29% heavier than bulbs of plants planted at 95 or 83 plants m^{-2}, respectively. Fresh mass of bulbs harvested from plants planted at a density of between 61 and 74 plants m^{-2} did not differ significantly from each other. Kanton *et al.* (2002) also reported a decrease in bulb fresh mass as plant population increased from 37.04 to 156.25 plants m^{-2}. Bulbs of plants planted at 37.04 plants m^{-2} were 128% heavier than bulbs from the highest plant population (156.25 plants m^{-2}). This was associated with sufficient leaf growth and space for bulb development with less populated plantings.

Table 5.4: Influence of plant population and sowing date on bulb fresh mass (g) and yield (t ha^{-1}) of onion cv. Jaquar

Plant Population (PP) (plants m^{-2})	Sowing Dates (SD)			Average (PP)
	11 May	25 May	8 June	
		Bulb fresh mass (g)		
95	39.32	45.40	28.67	37.80
83	43.35	53.05	35.79	44.06
74	53.74	53.76	49.17	52.22
67	68.07	49.89	49.33	55.76
61	64.42	58.00	61.94	61.45
Average (SD)	53.78	52.02	44.98	
$LSD_{T(0.05)}$	**PP = 10.34**	**SD = 6.80**	**PP x SD = ns**	
		Yield (t ha^{-1})		
95	37.45	43.24	27.31	36.00
83	36.12	44.20	29.82	36.71
74	39.81	39.82	36.42	38.68
67	45.38	33.26	32.88	37.17
61	39.04	35.15	37.53	37.24
Average (SD)	39.56	39.13	32.79	
$LSD_{T(0.05)}$	**PP = ns**	**SD = 5.08**	**PP x SD = ns**	

Even though plant population did not significantly influence yield, the highest yield was obtained from a plant population of 74 plants m^{-2} (38.68 t ha^{-1}) and the lowest from a plant population of 95 plants m^{-2} (36.00 t ha^{-1}). Interestingly, yield increased as plant population decreased from 95 to 74 plants per m^{-2}, but with a further decrease in plant population bulb yield also decreased, although not significantly. Various researchers reported on the increase in bulb yield with an increase in plant population (de Visser & van den Berg, 1998; Rumpel & Felczyński, 2000). Rumpel & Felczyński (2000) reported that onion yield increased from 29.8 to 32.6 t ha^{-1} when plant population increased from 60 to 100 plants m^{-2}. With a further increase to 140 plants m^{-2}, however, yield decreased to 31.1 t ha^{-1}. With a plant population lower than 60 plants m^{-2} onion yield also decreased from 26.4 to 20.5 t ha^{-1}. As plant population increased onion bulb yield decreased, possibly due to early maturity of bulbs. As bulbs mature earlier the period for leaf growth is also short resulting in a smaller LAI with less efficient light interception (de Visser, 1994).

As sowing date was delayed bulb fresh mass and yield decreased (Table 5.4). This difference in yield may be due to the fact that later sown plants switched from leaf blade production to bulb initiation almost at the same time as early sown plants resulting in a smaller leaf area index (LAI) with less light interception by the leaf canopy, than earlier sown plants (Brewster, 1994). In the current study plants sown late were harvested at almost the same time as early sown plants. Leilah *et al.* (2003) in Egypt, reported that a yield of 46.95 t ha^{-1} was obtained with the December planting, followed by 38.10 t ha^{-1} for the January and 31.80 t ha^{-1} for the February one.

The period from sowing to harvesting was shortened from 181 to 153 days by delaying the sowing date from 11 May to 8 June (Table 5.1). The growth period was between 21 and 28 days shorter for the late sown plants (25 May or 8 June) than for the early sown plants (11 May). The growth periods for the two lowest populated plantings (61 and 67 plants m^{-2}), sown late (8 June) were 7 days longer than that of the more densely populated plants sown on the same date (153 days). Rumpel & Felczyński (2000) also reported that neck-fall occurred 8 to 10 days earlier for the more densely populated planting of 140 plants m^{-2} than for the less densely populated planting of 20 plants m^{-2}.

Sowing date and plant population had a significant effect on bulb mass, eventually also influencing yield. The best sowing date for bulb mass from this experiment was from early May up to the end of May which was also true for 'Jaquar' in the earlier study reported in Chapter 4, Section 4.2.2.1. The highest bulb yield (38.68 t ha^{-1}) was obtained with a plant population 74 plants m^{-2} (Table 5.4). A plant population between 61 to 74 plants m^{-2} is therefore recommended for 'Jaquar'. This falls within the plant population range of 57-89 plants m^{-2} recommended by Hygrotech (2010).

5.2.2.2 Bulb diameter (size)

The interaction between plant population and sowing date significantly affected onion bulb diameter (Table 5.6). As plant population increased from 61 to 95 plants m^{-2} the size of bulbs decreased, irrespective of sowing date. All the bulbs were graded as medium size bulbs (40-69 cm), with the exception of bulbs harvested from plants sown on 11 or 25 May at the highest population planting of 95 plants m^{-2}. Bulb diameter responded differently to sowing date and plant population. Significantly larger bulbs were produced by plants at a density of between 61 and 74 plants m^{-2} and sown on either 11 May or 8 June than that of bulbs from plants sown at a density of between 83 and 95 plants m^{-2}. Bulbs harvested from the two lowest densities (61 or 67 plants m^{-2}) were significantly heavier than bulbs at the three highest populated plantings (74, 83 or 95 plants m^{-2}) when sowing took place on 25 May.

Table 5.6: Influence of plant population and sowing date on bulb diameter (mm)

Plant Population (PP) (plants m^{-2})	**Sowing Dates (SD)** 11 May	25 May	8 June	**Average (PP)**
95	39.22	39.74	42.68	40.55
83	44.45	44.29	45.02	44.59
74	55.47	46.98	54.33	52.26
67	64.97	59.61	54.14	59.57
61	68.94	63.96	59.24	64.05
Average (SD)	54.61	50.92	51.08	
$LSD_{T(0.05)}$	**PP = 5.16**	**SD = 3.39**	**PP x SD = 11.66**	

Prior research indicated that as plant population increased, bulb size declined (Farooq-Ch *et al.*, 1990; Islam *et al.*, 1999; Kanton *et al.*, 2002; Khan *et al.*, 2002). Hatridge-Esh & Bennett (1980) planted onions at four different plant populations (7, 40, 80 and 100 plants m^{-2}) in California and reported that bulb diameter decreased from 99 to 63 mm as plant population increased from 7 to 100 plants m^{-2}. This is caused by competition for nutrients and insufficient space restricting bulb enlargement when plant population increases. As indicated in Table 5.1, the highest percentage of medium bulbs (81.8-93.9%) occurred at a plant population of 74 plants m^{-2} for all three planting dates. When the two less dense populations are considered a lower percentage of medium bulbs occur with more extra small and small bulbs. The opposite was also true when plants are spaced closer, when more large bulbs occurred.

Although the average bulb size for all plant populations studied was between 40 to 64 mm (medium bulbs) (Table 5.6), the highest percentage of medium bulbs (86%) was obtained at a plant population of 74 plants m^{-2}, irrespective of sowing date.

5.2.2.3 Neck diameter

Neck diameter of 'Jaquar' bulbs was not significantly influenced by the interaction between plant population and sowing date (Table 5.7). Plant population and sowing date however, significantly affected neck diameter. Bulb neck diameter increased from 6.93 to 10.49 mm as plant population decreased from 95 to 61 plants m^{-2}. Significantly thicker necks were produced from plants sown at 61 or 67 plants m^{-2} than for necks of bulbs harvested from plants sown at 74, 83 or 95 plants m^{-2}. However, the necks of bulbs from plants sown at 61 or 67 plants m^{-2} did not differ significantly from each other and this was also true for bulbs of plants that were sown at a density of 83 or 95 plants m^{-2}. Onion plants sown late (8 June) produced bulbs with significantly thinner necks than those from earlier plantings (11 or 25 May).

Table 5.7: Influence of plant population and sowing date on neck diameter (mm)

Plant Population (PP)	Sowing Dates (SD)			Average
(plants m^{-2})	11 May	25 May	8 June	(PP)
95	7.09	7.39	6.31	6.93
83	8.16	8.17	6.69	7.67
74	10.25	9.35	7.15	8.92
67	10.62	11.18	8.42	10.07
61	11.36	12.11	8.01	10.49
Average (SD)	9.50	9.64	7.32	
$LSD_{T(0.05)}$	**PP = 1.26**	**SD = 0.83**	**PP x SD = ns**	

Onion bulbs with thinner necks (6-9 mm) can be stored for a longer period (Mohanty & Prusti, 2001; Jilani & Ghaffoor, 2003) as they dry and close up quickly, so minimizing pathogen infection (Brewster *et al.*, 1991) and moisture loss from the bulbs and maintaining bulb turgidity (Thamizharasi & Narasimham, 1991). Plant population (Dawar *et al.*, 2005, 2007), fertilizers such as phosphorus and nitrogen (Brewster *et al.*, 1987; Shaheen *et al.*, 2007), soil type as well as delayed maturity (Brewster *et al.*, 1987) and cultivar (Naz & Amjad, 2004) all influence neck diameter. As onion plant population increased from 20 to 40 plants m^{-2}, neck diameter decreased significantly from 19 to 16 mm (Farooq-Ch *et al.*, 1990). The reason for the increase in neck diameter as plant population decreases may be due to larger plants that occur at lower plant populations. Current results showed that neck diameter of bulbs decreased with a delayed sowing date and according to Brewster (1994) late sown plants will start initiating bulbs at the same time as early sown plants, but the later sown plants will still be small, resulting in thinner bulb necks.

From the results, it is evident that plant population and sowing date influenced final neck size of onion bulbs. The thinnest necks were obtained with plant populations ranged from 74 to 95 plants m^{-2} and a sowing date of 8 June. In the previous study, Chapter 4, Section 4.2.2.3, 'Jaquar' bulbs harvested from plants sown late (21 May) also produced the thinnest necks, thinner than those from earlier sowing dates (30 April or 7 May). As plant population declined from 61 plants m^{-2} in 2009 to 41 plants m^{-2} in 2010 (Chapter 4, Section 4.2.2.3), neck size also declined from 17.69 to 9.09 mm.

5.2.2.4 Bulb firmness

Bulb firmness was significantly affected by both plant population and sowing date. The interaction between these two factors was, however, not significant (Table 5.8).

Table 5.8: Influence of plant population and sowing date on bulb firmness (mm)

Plant Population (PP) (plants m^{-2})	Sowing Dates (SD) 11 May	25 May	8 June	Average (PP)
95	104.00	105.68	90.65	100.11
83	100.91	102.66	74.48	92.68
74	77.55	85.82	56.57	73.31
67	77.95	73.30	66.35	72.53
61	80.70	72.90	63.27	72.29
Average (SD)	88.22	88.07	70.26	
$LSD_{T(0.05)}$	**PP = 9.21**	**SD = 6.06**	**PP x SD = ns**	

As plant population decreased from 95 to 62 plants m^{-2}, bulbs got firmer. Bulbs harvested from plants sown at a density of 95 or 83 plants m^{-2} produced significantly softer bulbs than those harvested from plants at 74, 67 or 61 plants m^{-2}. Plants sown late (8 June) produced significantly firmer bulbs than when sown earlier (11 May or 25 May). This can be attributed to fact that rain occurred just before harvesting bulbs of the late sown plants (8 June). The same trend was observed on this cultivar in the earlier study (Chapter 4, Section 4.2.2.4). Chung (1989) reported that when bulbs receive water close to harvesting bulb firmness will increase.

A plant population of between 61 and 74 plants m^{-2} and a late sowing date (8 June) resulted in the firmest bulbs.

5.2.2.5 Bolting

No bolting occurred and corresponded to results of the previous study (Chapter 4, Section 4.2.2.5), although low temperatures (3.8-9.1°C) (Chapter 3, Table 3.1) occurred during the expected bulb initiation period. This again indicates that 'Jaquar' is less sensitive to low temperatures than other cultivars (Agic *et al.*, 2007).

5.2.2.6 Bulb shape

'Jaquar' is known for its globe shaped bulbs (Hygrotech, 2009). As indicated in Section 2.5.3.3, bulb shape in this study was visually determined using the norms of Boyhan & Kelley (2008). From the current results, none of the plant populations or sowing dates produced globe shaped bulbs, and this was also true for the earlier study reported on in Chapter 4, Section 4.2.2.6. Bulb shape changed with plant population. At a population of 95 or 83 plants m^{-2} bulbs were spindle shaped (epllitic) and changed to oval shape as plant population decreased to 74 or 67 plants m^{-2}. Bulb shape changed from oval shape to a broad reversed (top) shape with a further decrease in plant population to 61 plants m^{-2}. The reason for the change in bulb shape was the limited space available for each bulb to develop in. Elongated bulbs are the result of squeezing against each other (Hygrotech, 2010). McGeary (1985) reported a decline in number of round bulbs (13.3%) when population increased from 178 to 1 600 plants m^{-2}. Current results showed that all the bulbs (100%) changed shape as plant population changed.

5.3 SUMMARY AND CONCLUSIONS

The manipulation of plant population is a sensitive agronomic practice which cannot be ignored as it influences growth, yield and bulb quality (bulb mass, size, firmness and shape) of onions. Plant height was found to decrease significantly as plant population increased, although plant population did not significantly influence the number of leaves produced by onion plants. Less dense plant populations (61 and 67 plants m^{-2}) produced significantly taller plants, while denser plant populations (74-95 plants m^{-2}) produced more leaves, although not significantly more. Sowing date significantly affected plant height but not the number of leaves. The best vegetative growth was attained when plants were sown during the middle of May.

Plant population significantly affected bulb fresh mass, with the bulb mass decreasing as plant population increased, but not bulb yield. The highest bulb yield was obtained at 74 plants m^{-2} and declined as plant population increased further. Both bulb fresh mass and yield were significantly reduced by the late sowing date (8 June). Onions produced the highest bulb fresh mass and yield when sowing was done during May.

It is evident that plant population influences growth, bulb yield and quality. Sowing date significantly influenced most parameters measured, with the exception of leaf number and bulb shape. Although late sowing (end May to beginning of June) tended to improve some bulb quality parameters (neck diameter and firmness), the best yield was obtained from plants sown from early to mid May at a plant population of 74 plants m^{-2}.

REFERENCES

AGIC, R., POPSIMONOVA, G., JANKULOVSKI, D. & MARTINOVSKI, G., 2007. Winter onion susceptibility to premature bolting depending on the variety and the sowing date. *Acta Hort.* 729, 271-276.

AMANULLAH, J., HASSAN, M.J., NAWAB, K. & ALI, A., 2007. Response of specific leaf area (SLA), leaf area index (LAI) and leaf area ration (LAR) of maize (*Zea mays* L.) to plant density rate and timing of nitrogen application. *World Appl. Sci. J.* 2, 235-243.

BOSCH SERRA, A.D. & CURRAH, L., 2002. Agronomy of onions. *In*: H.D. Rabinowitch & L. Currah (eds.). Allium crop science: recent advances. CAB International, Wallingford, United Kingdom.

BOYHAN, G. & KELLEY, W.T., 2008. Variety selection and characteristics. *In:* G.E. Boyhan & W.T. Kelley (eds.). Onion production guide. Cooperative Extension. The University of Georgia, Georgia, United States of America.

BREWSTER, J.L., 1990. The influence of cultural and environmental factors on the time of maturity of bulb onion crops. *Acta Hort.* 267, 289-296.

BREWSTER, J.L., 1994. Onions and other vegetable alliums. 1^{st} edn., CAB International, Wallingford, United Kingdom.

BREWSTER, J.L., 2008. Onions and other vegetable alliums. 2^{nd} edn., CAB International, Wallingford, United Kingdom.

BREWSTER, J.L., LAWES, W. & WHITLOCK, A.J., 1987. The phenology of onion bulb development at different sites and its relevance to incomplete bulbing ('thick-necking'). *J. Hort. Sci.* 62, 371-378.

BREWSTER, J.L., ROWSE, H.R. & BOSCH, A.D., 1991. The effects of sub-seed placement of liquid N and P fertilizer on the growth and development of bulb onions over a range of plant densities using primed and non-primed seed. *J. Hort. Sci.* 66, 551-557.

CHUNG, B., 1989. Irrigation and bulb onion quality. *Acta Hort.* 247, 233-237.

COMRIE, A.G., 1997. How to grow onions. Onions E.1. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

CRAMER, C.S., 2003. Performance of fall-sown onion cultivars using four seeding dates. *J. Amer. Soc. Hort. Sci.* 128, 472-478.

DAWAR, N.M., WAZIR, F.K., DAWAR, M. & DAWAR, S.H., 2005. Effect of planting density on the performance of three varieties of onion under the agro-climatic conditions of Peshawar. *Sarhad J. Agric.* 21, 545-550.

DAWAR, N.M., WAZIR, F.K., DAWAR, M. & DAWAR, S.H., 2007. Effect of planting density on growth and yield of onion varieties under climatic conditions of Peshawar. *Sarhad J. Agric.* 23, 911-917.

DE VISSER, C.L.M., 1994. ALCEPAS, an onion growth model based on SUCROS87. I. Development of the model. *J. Hort. Sci.* 69, 501-518.

DE VISSER, C.L.M. & VAN DEN BERG, W., 1998. A method to calculate the size distribution of onions and its use in an onion growth model. *Sci. Hortic.* 77, 129-143.

DELLACECCA, V. & LOVATO, A.F.S., 2000. Effects of different plant densities and planting systems on onion (*Allium cepa* L.) bulb quality and yield. *Acta Hort.* 533, 197-203.

EKSTEEN, G.J., VAN DEN KLASHORST, E. & VAN ZIJI, B., 1997. Onions for export harvesting, handling and storage. Onions J.2. Agricultural Research Council, Vegetable and Ornamental Plant Institute, Pretoria, South Africa.

FAROOQ-CH, M., MAHMOOD, K., KHAN, M.A. & QADIR, A., 1990. Effect of plant density on plant growth, size and yield of onion. *Pakistan J. Agric. Res.* 11, 239-242.

GARDNER, F.P., PEARCE, R.B. & MITCHELL, R. L., 1985. Physiology of crop plants. The Iowa State University Press, Ames, Iowa, United States of America.

HATRIDGE-ESH, K.A. & BENNETT, J.P., 1980. Effects of seed weight, plant density and spacing on yield responses of onion. *J. Hort. Sci.* 55, 247-252.

HYGROTECH, 2009. Onion variety profiles: Short day length. Hygrotech Sustainable Solutions. www.hygrotech.com (Accessed 10/05/09).

HYGROTECH, 2010. Production guidelines of onions. Hygrotech Sustainable Solutions. Hygrotech, Pretoria, South Africa.

IBRAHIM, N.D., 2010. Growth and yield of onion (*Allium cepa* L.) in Sokoto, Nigeria. *Agric. Biol. J. N. Am.* 1, 556-564.

ISLAM, M.K., AWAL, M.A., AHMED, S.U. & BATEN, M.A., 1999. Effect of different set sizes, spacings and nitrogen levels on the growth and bulb yield of onion. *Pak. J. Biol. Sci.* 2, 1143-1146.

JILANI, M.S., 2004. Studies on the management strategies for bulb and seed production of different cultivars of onion (*Allium cepa* L.). M.Sc. dissertation, North West Frotier Province of Pakistan. Agriculture University, Peshawar, Pakistan.

JILANI, M.S. & GHAFFOOR, A., 2003. Screening of local varieties of onion for bulb formation. *Int. J. Agric. Biol.* 5, 129-133.

JILANI, M.S., KHAN, M.Q. & RAHMAN, S., 2009. Planting densities effect on yield and yield components of onion (*Allium cepa* L.). *J. Agric. Res.* 47, 397-404.

JONES, H.A. & MANN, L.K., 1963. Onions and other allies. Interscience Publishers, Inc. New York, United States of America.

KANTON, A.L., ABBEY, L., HILLA, R.G., TABIL, M.A. & JAN, N.D., 2002. Density affects plant development and yield of bulb onion (*Allium cepa* L.) in northern Ghana. *J. Veg. Crop Prod.* 8, 15-25.

KHAN, H., IQBAL, M., GHAFFOOR, A. & WASEEM, K., 2002. Effect of various plant spacing and different nitrogen levels on the growth and yield of onion (*Allium cepa* L.). *J. Biol. Sci.* 2, 545-547.

KHAN, M.A., HASAN, M.K., MIAH, M.A.J., ALAM, M.M. & MASUM, A.S.M.H., 2003. Effect of plant spacing on the growth and yield of different varieties of onion. *Pakistan J. Biol. Sci.* 6, 1582-1585.

KHOKHAR, K.M., HADLEY, P. & PEARSON, S., 2007. Effect of cold temperature durations of onion sets in store on the incidence of bolting, bulbing and seed yield. *Sci. Hortic.* 112, 16-22.

LAI, S.H., CHEN, N.C., SHANMUGASUNDARAM, S. & TSOU, S.C.S., 1994. Evaluation of onion cultivars at AVRDC. *Acta Hort.* 358, 221-228.

LEILAH, A.A., EL-KALLA, S.A., MOSTAFA, A.K. & AFIFI, H.M.A., 2003. Performance of some local Egyptian onion strains under different planting dates. *Sci. J. King Faisal Univ.* 4, 119-136.

LESKOVAR, D.I. & VAVRINA, C.S., 1999. Onion growth and yield are influenced by transplant tray cell size and age. *Sci. Hortic.* 80, 133-143.

McGEARY, D.J., 1985. The effects of plant density on the shape, size, uniformity, soluble solids content and yield of onions suitable for pickling. *J. Hort. Sci.* 60, 83-87.

MOHANTY, B.K. & PRUSTI, A.M., 2001. Performance of common onion varieties in Kharif seasons. *J. Trop. Agric.* 39, 21-23.

MONDAL, M.F., BREWSTER, J.L., MORRIS, G.E.L. & BUTLER, H.A., 1986. Bulb development in onion (*Allium cepa* L.). I. Effects of plant density and sowing date in field conditions. *Ann. Bot.* 58, 187-195.

MULUNGU, L.S., REUBEN, S.O.W.M., NCHIMBI-MSOLLA, S., MISANGU, R.N., MBILINYI, L.B. & MACHA, M.M., 1998. Performance of nine exotic and local onion (*Allium cepa* L.) genotypes grown under a dry season tropical condition at Morogoro, Tanzania. 1. Yield and its components. *S. Afr. J. Sci.* 94, 451-454.

NAZ, S. & AMJAD, M., 2004. Production potential of diverse onion genotypes raised through sets. *Pak. J. Agric. Sci.* 41, 3-4.

PAKYÜREK, Y., ABAK, K., SARI, N. & GÜLER, H.Y., 1994. Effets of sowing dates and plant densities on the yield and quality of some onion varieties in southeast Anatolia. *Acta Hort.* 371, 209-214.

RABINOWITCH, H.D., 1979. Doubling of onion bulbs as affected by size and planting date of sets. *Ann. Appl. Biol.* 93, 63-66.

RAHMAN, M.A., SAHA, R.S., SALAM, M.A., MASUM, A.S.M.H. & CHOWDHURY, S.S., 2002. Correlation and path coefficient analysis in onion (*Allium cepa* L.). *J. Biol. Sci.* 2, 531-532.

RICHWINE, P.A., 1990. Effect of fall planting date on bulb yield of 'sweet winter' onion in the rolling plains of Texas. *HortScience* 25, 981.

RUMPEL, J. & FELCZYŃSKI, K., 2000. Effect of plant density on yield and bulb size of direct sown onions. *Acta Hort.* 533, 179-185.

SHAHEEN, A.M., AISHA, M.M.A., ALI, H. & RIZK, F.A., 2007. Natural and chemical phosphorus fertilizers as affected onion plant growth, bulbs yield and its some physical and chemical properties. *Aust. J. Basic Appl. Sci.* 1, 519-524.

SHOCK, C.C., FEIBERT, E. & SAUNDERS, L.D., 2004. Plant population and nitrogen fertilization for subsurface drip irrigated onion. *HortScience* 39, 1722-1727.

SHOCK, C.C., FEIBERT, E. & SAUNDERS, L.D., 2005. Single centered and supper colossal bulbs from yellow onion cultivars. *HortTech.* 15, 399-408.

TARPAGA, M.W.V., ALBERT, R. & ZOUMBIESSE, T., 2011. Effects of seasons of bulb seed production on the early bolting of onion (*Allium cepa* L.) cv. 'Violet de Galmi'. *J. Appl. Biosci.* 40, 2652-2658.

THAMIZHARASI, V. & NARASIMHAM, P., 1991. Water vapour sorption and transmission by onion (*Allium cepa.* L) scale under different temperature and humidity conditions. *Sci. Hortic.* 46, 185-196.

WEERASINGHE, S.S. & FORDHAM, R., 1994. The effects of plant density on onions established from multiseeded transplants. *Acta Hort.* 371, 97-104.

CHAPTER 6

STORAGE LIFE OF DIFFERENT ONION CULTIVARS AS AFFECTED BY PLANT POPULATION AND PLANTING DATE

6.1 INTRODUCTION

Onion storage is a valuable practice that provides bulbs for marketing when there is an undersupply on the market and prices are high. There is a high demand for onions throughout the year but prices fluctuate according to supply. The statistics from the Bloemfontein Fresh Produce Market during 2009, indicated that during periods of over-supply the market price is as low as R 2 738.97 ton^{-1}, but as soon as there is an under-supply prices increased to R 4 790.52 ton^{-1} (Department of Agriculture, Forestry and Fisheries, 2009). Successful storage of onions is therefore a challenge for producers so that they can market bulbs at times when prices are high on the market. The aim of storing onions is to maintain quality for as long as possible and to extend the availability of onions (Hansen, 1999). Onion bulbs are naturally suited for storage as they are dormant after harvesting. Studies conducted by Ramin (1999) and Grevsen & Sorensen (2004) indicated that onion bulbs can be stored for 8 to 9 months without sprouting. However, storability depends on a number of factors such as storage structure and conditions (temperature, humidity and ventilation) (Brewster, 2008), cultivar type (Msuya *et al.*, 2005) and environmental conditions during growth (Abbey *et al.*, 2000), as well as pre- and post-harvest treatments (Toledo *et al.*, 1984). According to Adamicki (2005) onions can be stored for a long period at 0.5°C and a relative humidity of 75%.

Various storage methods exist for onion bulbs. In countries with a dry climate, such as Argentina and Egypt, onions are stored in the field, which is a cheap and effective storage method (Gubb & MacTavish, 2002). Onions are heaped and covered with straw or plastic sheet to protect the bulbs from sunburn or occasional rains. In Thailand, onion bulbs are stored by tying leaves in bunches and hanging them from poles either under the farmer's house or in sheds (Peters *et al.*, 1994). Refrigerated storage is a more expensive but effective way of storing onion bulbs for a long period (Smittle, 1988).

The major problem during storage is the loss of bulbs, which may be due to several factors, the most important one being post-harvest diseases (Wright & Grant, 1997). Losses due to post-harvest diseases during storage can range from 10 to 50% (Rajapakse & Edirimanna, 2002). Various pathogens such as *Botrytis allii* (Prithiviraj *et al.*, 2004; Geary *et al.*, 2006), *Erwinia carotovora* subsp. *carotovora* (Mohan, 1995) and *Aspergillus niger* (Abd-Alla *et al.*, 2006; Ullah *et al.*, 2008) are responsible for post-harvest rotting. Warm storage conditions (24-30°C) and a high relative humidity (78-81%) can be the cause of black mould (*Aspergillus niger*) infection during storage (Sumner, 1995). Cultural practices such as harvesting time, topping and moisture present in the neck of the bulb at harvesting can influence rotting of bulbs by *Pseudomonas marginalis* and *Pseudomonas carotovorum* subsp. *carotovorum* during storage (Schroeder & Du Toit, 2010). The level of rotting during storage varies from season to season due to prevailing weather conditions during growth and harvesting, curing and storage conditions (Wright & Grant, 1997; Adamicki, 2005).

Sprouting can also cause bulb losses during storage (Hurst *et al.*, 1985; Benkeblia *et al.*, 2002; Gautam *et al.*, 2006). Storage temperatures ranging from 10-20°C (Benkeblia *et al.*, 2002) influence the development and rate of sprouting. No sprouting occurs at storage temperature between -1 and 1°C or between 25 and 30°C (Miedema, 1994). Genetic composition (Miedema, 1994), time of harvesting (Grevsen & Sorensen, 2004) and application of nitrogen fertilizer close to harvesting (Sorensen & Grevsen, 2001, 2002) are also known to affect sprouting. Sprouted bulbs are of a low quality and are not allowed in first class graded onions (Grevsen & Sorensen, 2004).

Any loss in mass during storage of onion bulbs causes a reduction in marketable mass (Mozumder *et al.*, 2007). High storage temperatures (25°C to 39°C) and a high relative humidity (90%) promote rotting, transpiration and respiration which influence bulb mass (Msuya *et al.*, 2005; Biswas *et al.*, 2010). The loss of moisture from bulbs may be prevented by maintaining a relative humidity of between 65 to 75% during storage (Ramin, 1999). The rate of water loss is higher in short day cultivars causing them to have a poor storage compared to long day cultivars (Kopsell & Randle, 1997; Ramin, 1999). Storage of onion bulbs is also associated with the type of cultivar (Fustos *et al.*, 1994). Long day cultivars have a potential for longer storage, 1 to 2 months longer than short day cultivars (Hygrotech, 2009a & b). However, some new short day cultivars can be stored for longer periods, almost the same as some intermediate day cultivars. For example, the short day cultivar 'Red Creole' can be stored for up to six months. Currah & Proctor (1990) as cited by Ko *et al.* (2002) reported that 'Violet de Galmi' and 'Yod Aleph', both short day cultivars, can be stored for up to seven months.

Long term storage of onion bulbs is desired for continuous supply to the market and has a great influence on market value (Suzuki & Cutcliffe, 1989; Department of Agriculture, Forestry and Fisheries, 2009). This experiment was, therefore, conducted to evaluate the storage capability of different onion cultivars sown on different dates.

6.2 RESULTS AND DISCUSSION

Bulbs used in this experiment were those harvested from the three trials reported previously in Chapters 4 and 5. The methods are discussed in Chapter 3, Section 3.5.

The storage of onion bulbs were terminated as soon as the bulbs were no longer visually attractive and marketable. Storage data was taken every three weeks up to 18 weeks after commencement of storage in 2009, and up to 15 weeks in 2010. Moisture loss from bulbs was only measured during 2010.

6.2.1 Influence of cultivar and sowing date on storage of onions

6.2.1.1 Storage duration

The storage duration of onion bulbs stored under different conditions was not affected by sowing dates in either 2009 or 2010 (Figure 6.1a-d). Interestingly, 'Charlize' (short day cultivar), 'Jaquar' and 'Python' (two intermediate day cultivars) lasted 126 days under both storage conditions, whereas 'South Wester' (mid-intermediate day cultivar) only lasted 105 days in the cold room and 98 days under room temperature conditions during 2009 (Figure 6.1a & b). During 2010, the mid-intermediate day cultivar Ceres Gold, also only lasted 63 days compared to 105 days for 'Charlize', 'Jaquar' and 'Python' under both storage conditions (Figure 6.1c & d).

Different researchers indicated that climate conditions during the growth season influenced the storage duration of onion bulbs and may also influence the growth period before harvesting the bulbs (Rutherford & Whittle, 1982; Adamicki, 2005; Mallor *et al.*, 2011; Tarpaga *et al.*, 2011). The current study indicated that the storage duration for the same cultivar differed between the two seasons (Figure 6.1). The growth period (from sowing to harvesting) for 'Charlize', 'Jaquar' and 'Python' was between two and four weeks longer in 2009 than in 2010 (Table 4.1) allowing bulbs to accumulate carbohydrates over a longer period in 2009 than in 2010 that may have enabled bulbs to be stored for 21 days longer.

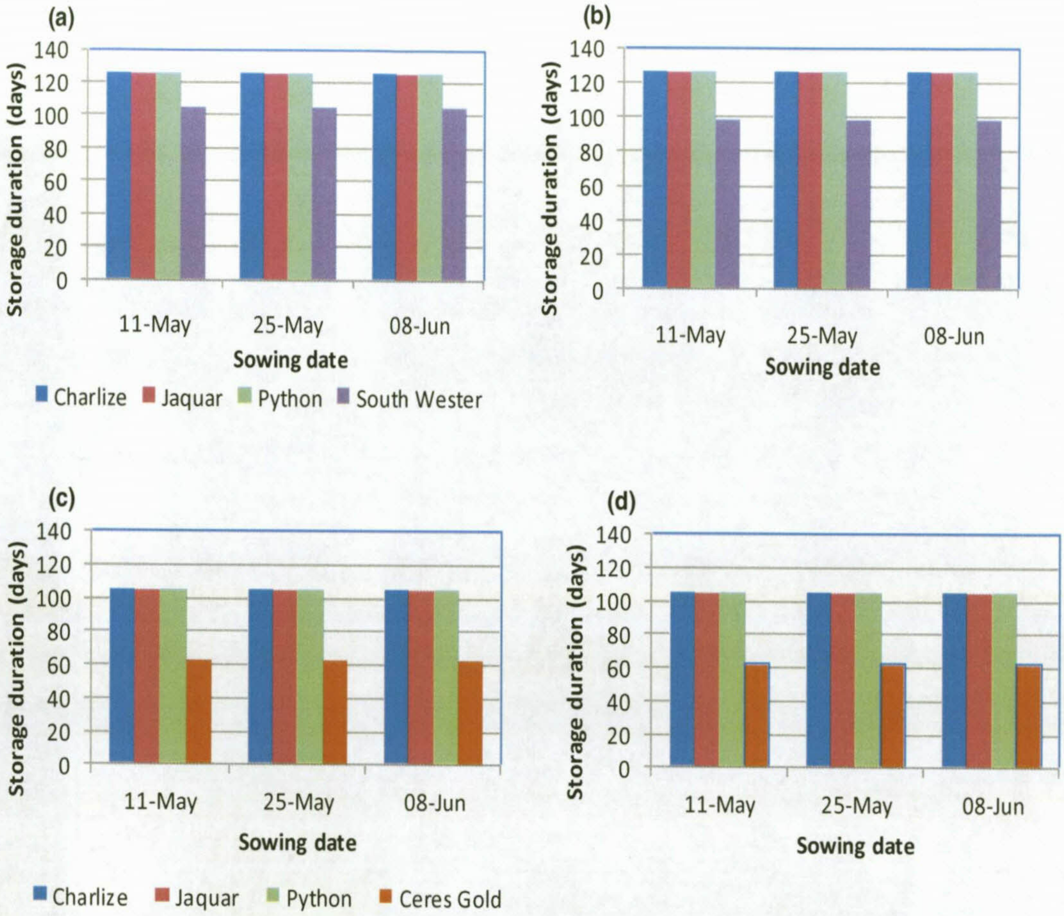


Figure 6.1: Storage duration of different onion cultivars sown at different dates stored under different conditions: (a) room temperature (±25°C) and (b) cold room temperature (5°C) during 2009; (c) room temperature (±25°C) and (d) cold room temperature (5°C) during 2010

The large bulbs with thick necks produced by the two mid-intermediate day cultivars ('South Wester' and 'Ceres Gold') may be the reason for their shorter storage periods compared to other cultivars. In Chapter 4, Section 4.2.2.2, it was reported that 'South Wester' bulbs were larger (82.51 mm) than the other cultivars in 2009, while in 2010 'Ceres Gold' had larger bulbs (60.06 mm). Necks of 'South Wester' and 'Ceres Gold' were thicker (22.55 and 18.96 mm, respectively) compared to other cultivars (Chapter 4, Section 4.2.2.3). Ward (1979) reported that small (45-50 mm) or medium (50-60 mm) bulbs lasted better than large bulbs (60-70 mm) under storage. Onion bulbs with thinner necks have a better storage life (Mohanty & Prusti, 2001; Jilani & Ghaffoor, 2003) due to the fact that stored bulbs lose more moisture through the thicker than thinner necks (Thamizharasi & Narasimham, 1991).

The storage period of 'Charlize' (short day cultivar) and 'Jaquar' (early-intermediate day cultivar) ranged between 2 and 3 months whereas 'Python' (early-intermediate day cultivar) ranged between 3.5 and 4.5 months, and 'South Wester' and 'Ceres Gold' (two mid-intermediate day cultivars) ranged between 2 and 3.5 months (Figure 6.1a–d). However, 'South Wester', 'Ceres Gold', 'Python' and 'Jaquar' are known for long storage periods of up to five and seven months (Hygrotech, 2009b).

6.2.1.2 Black mould (*Aspergillus niger*)

A number of bulbs were lost due to black mould (*A. niger*) infection (Figure 6.2) during both 2009 and 2010 trials (Table 6.1 & 6.2). During 2009, disease incidence occurred after as little as three weeks of storage (Table 6.1), while in 2010 it was only visible at the end of the storage period (15 weeks of storage). All bulbs stored under room temperature were infected (Table 6.2), but none of the bulbs stored in the cold room were infected.

Figure 6.2: Onion bulbs infected with black mould (*A. niger*)

Onions sown late (21 May) and stored under room temperature after harvesting in 2009, showed a much higher infection percentage of black mould than all the other sowing dates, irrespective of cultivar (Table 6.1). The same trend was observed for bulbs stored in the cold room, but the percentage infection was much lower for all sowing dates.

A much higher percentage of 'South Wester' bulbs were lost due to black mould infection compared to the other cultivars when stored under room temperature, in 2009. When sowing was done on 30 April, 69.70% of 'South Wester' bulbs were lost, followed by 9.09% of 'Jaquar' and 'Charlize' and then 3.03% of 'Python' bulbs. When onions were sown on 7 May, 57.58% of 'South Wester' bulbs were lost due to black mould infection followed by 30.30% of 'Jaquar' and 15.15% of both 'Charlize' and 'Python'. When sowing was done on 21 May, 'South Wester' and 'Jaquar' showed a higher percentage bulb loss due to black mould compared to 'Charlize' and 'Python' in both storage conditions.

Table 6.1: Number and total percentage bulb loss due to black mould (*A. niger)* infection of different onion cultivars sown on different dates in 2009 (n=33)

Storage	**Sowing date**	**Cultivar**	**Storage period (weeks)**						**Total**
			3	**6**	**9**	**12**	**15**	**18**	**loss (%)**
Room	30 April	Charlize	0	0	0	0	1	2	9.09
		Jaquar	2	0	0	1	0	0	9.09
		Python	0	0	0	0	0	1	3.03
		South Wester	16	0	2	5	0	0	69.70
	7 May	Charlize	0	0	0	2	3	0	15.15
		Jaquar	0	7	0	1	0	2	30.30
		Python	1	0	3	0	1	0	15.15
		South Wester	10	3	4	2	0	0	57.58
	21 May	Charlize	0	7	2	1	1	0	33.33
		Jaquar	0	13	1	2	1	3	60.60
		Python	0	0	0	0	10	0	30.30
		South Wester	18	0	0	4	0	0	66.67
Cold room-	30 April	Charlize	0	0	0	0	0	0	0.00
		Jaquar	0	0	0	0	0	1	3.03
		Python	0	0	0	0	0	0	0.00
		South Wester	0	0	2	0	0	0	6.06
	7 May	Charlize	0	0	0	0	0	0	0.00
		Jaquar	0	2	4	0	0	0	18.18
		Python	0	0	0	0	0	0	0.00
		South Wester	2	2	0	0	0	0	12.12
	21 May	Charlize	0	2	2	2	0	0	18.18
		Jaquar	0	0	0	5	0	2	21.21
		Python	0	0	0	0	0	2	6.06
		South Wester	2	2	0	0	0	0	12.12

Table 6.2: Number and total percentage bulb loss due to black mould (*A. niger)* infection of different cultivars sown on different dates in 2010 (n=33)

Storage	Sowing date	Cultivar	Storage period (weeks)					Total loss (%)
			3	6	9	12	15	
Room	11 May	Charlize	0	0	0	0	33	100
		Jaquar	0	0	0	0	33	100
		Python	0	0	0	0	33	100
		Ceres Gold	0	0	0	0	33	100
	25 May	Charlize	0	0	0	0	33	100
		Jaquar	0	0	0	0	33	100
		Python	0	0	0	0	33	100
		Ceres Gold	0	0	0	0	33	100
	8 June	Charlize	0	0	0	0	33	100
		Jaquar	0	0	0	0	33	100
		Python	0	0	0	0	33	100
		Ceres Gold	0	0	0	0	33	100
Cold Room	11 May	Charlize	0	0	0	0	0	0
		Jaquar	0	0	0	0	0	0
		Python	0	0	0	0	0	0
		Ceres Gold	0	0	0	0	0	0
	25 May	Charlize	0	0	0	0	0	0
		Jaquar	0	0	0	0	0	0
		Python	0	0	0	0	0	0
		Ceres Gold	0	0	0	0	0	0
	8 June	Charlize	0	0	0	0	0	0
		Jaquar	0	0	0	0	0	0
		Python	0	0	0	0	0	0
		Ceres Gold	0	0	0	0	0	0

Black mould infection increased with delayed sowing dates (7 and 21 May) when bulbs were stored under cold room temperatures. 'South Wester' and 'Jaquar' showed the highest infection percentage of black mould with 12.12 and 21.21%, respectively. Results indicated that late sowing increased the incidence of black mould and that some cultivars such as Charlize and Python showed some resistance to black mould.

The intensity of black mould infection between the two seasons was not the same, indicating the climate conditions during harvesting may have played a role. Black mould infection was reported as early as the third week of storage in 2009 and only during the last week of storage (week 15) in 2010. During 2009, more rain occurred five days prior to harvesting (42 mm) than during 2010 (18 mm), and this may have led to the earlier infection during storage. According to Thamizharasi & Narasimham (1991) rain can lead to increased ambient relative humidity and also the susceptibility of onion bulbs to black mould infection. Onion cultivars also differ in their susceptibility to black mould infection and this was particularly evident in 2009. 'Charlize' and 'Python' showed more resistance to black mould infection than 'South Wester' and 'Jaquar' (Table 6.1). The average temperature in room storage was 26°C, and in the cold room 5°C. It has been reported that temperatures ranging from 28 to 34°C (Tyson & Fullerton, 2004) enhance the germination of black mould spores and may explain the lower infection rate in the cold room.

It is clear from this data that rainfall during harvesting may have had an influence on black mould infection during storage but that storage temperatures may also play a role.

6.2.1.3 Sprouting

Another minor cause of bulb losses during storage was sprouting (Figure 6.3). Onion bulbs are dormant after harvesting and sprouting can occur during storage after dormancy is broken and leaves will emerge and grow from the bulbs (Yasin & Bufler, 2007; Nam *et al.*, 2011).

Figure 6.3: Onion bulbs that sprouted during storage under both room and cold room conditions

No clear trend could be detected between the two seasons (Tables 6.3 & 6.4). Sprouting varied between cultivars, sowing dates and storage conditions. From the current study, sprouting was first noted after 42 days of storage for bulbs under room conditions, whereas in the cold room it was first noted after 63 days, during 2009. 'South Wester' (9.09%) and 'Python' (3.03%) bulbs harvested from plants sown on 7 May and stored under room temperature sprouted. In the cold room, only 'Charlize' and 'Jaquar' bulbs harvested from plants sown on 7 May or 21 May sprouted (Table 6.3).

Table 6.3: Number and total percentage of bulbs lost due to sprouting of different onion cultivars sown on different dates during 2009 (n=33)

Storage	Sowing date	Cultivar	Storage duration (weeks)						Total loss (%)
			3	6	9	12	15	18	
Room	30 April	Charlize	0	0	0	0	0	0	0.00
		Jaquar	0	0	0	0	0	0	0.00
		Python	0	0	0	0	0	0	0.00
		South Wester	0	0	0	0	0	0	0.00
	7 May	Charlize	0	0	0	0	0	0	0.00
		Jaquar	0	0	0	0	0	0	0.00
		Python	0	0	1	0	0	0	3.03
		South Wester	0	3	0	0	0	0	9.09
	21 May	Charlize	0	0	0	0	0	0	0.00
		Jaquar	0	0	0	0	0	0	0.00
		Python	0	0	0	0	0	0	0.00
		South Wester	0	0	0	0	0	0	0.00
Cold Room	30 April	Charlize	0	0	0	0	0	0	0.00
		Jaquar	0	0	0	0	0	0	0.00
		Python	0	0	0	0	0	0	0.00
		South Wester	0	0	0	0	0	0	0.00
	7 May	Charlize	0	0	1	0	0	0	3.03
		Jaquar	0	2	0	0	0	0	6.06
		Python	0	0	0	0	0	0	0.00
		South Wester	0	0	0	0	0	0	0.00
	21 May	Charlize	0	0	0	2	0	0	6.06
		Jaquar	0	0	1	0	0	0	3.03
		Python	0	0	0	0	0	0	0.00
		South Wester	0	0	0	0	0	0	0.00

During 2010, no visible sprouting was noticed on any of the cultivars stored under room temperature (Table 6.4). Onion bulbs stored in the cold room differed in the percentage of sprouting that occured between the different cultivars. Only 'Python' and 'Jaquar' bulbs harvested from plants sown early (11 May) sprouted and only for 'Jaquar' bulbs (6.06%) when sowing was delayed to 25 May. When sowing was further delayed to 8 June, both 'Python' (42.42%) and 'Jaquar' (24.24%) bulbs sprouted in the cold room.

Table 6.4: Number and total percentage of bulbs lost due to sprouting of different onion cultivars sown on different dates during 2010 (n=33)

Storage	Sowing date	Cultivar	Storage period (weeks)					Total
			3	6	9	12	15	loss (%)
Room	11 May	Charlize	0	0	0	0	0	0.00
		Jaquar	0	0	0	0	0	0.00
		Python	0	0	0	0	0	0.00
		Ceres Gold	0	0	0	0	0	0.00
	25 May	Charlize	0	0	0	0	0	0.00
		Jaquar	0	0	0	0	0	0.00
		Python	0	0	0	0	0	0.00
		Ceres Gold	0	0	0	0	0	0.00
	8 June	Charlize	0	0	0	0	0	0.00
		Jaquar	0	0	0	0	0	0.00
		Python	0	0	0	0	0	0.00
		Ceres Gold	0	0	0	0	0	0.00
Cold Room	11 May	Charlize	0	0	0	0	0	0.00
		Jaquar	0	0	1	2	0	9.09
		Python	0	0	3	0	0	9.09
		Ceres Gold	0	0	0	0	0	0.00
	25 May	Charlize	0	0	0	0	0	0.00
		Jaquar	0	0	0	2	0	6.06
		Python	0	0	0	0	0	0.00
		Ceres Gold	0	0	0	0	0	0.00
	8 June	Charlize	0	0	0	0	0	0.00
		Jaquar	0	0	2	6	0	24.24
		Python	0	0	7	7	0	42.42
		Ceres Gold	0	0	0	0	0	0.00

From the result of this study it is apparent that sprouting was more evident in bulbs from late sown plants and particularly when stored in the cold room (5°C). This may be due to the fact that bulb dormancy is broken at temperatures ranging between 5 and 20°C, while storage temperatures of between 25 and 30°C are known for inhibiting sprouting of bulbs (Gubb & MaTavish, 2002). Ramin (1999) reported that temperature of 25°C during storage induces dormancy in bulbs.

Ward (1979) reported that the commencement of sprouting in onion is not related to the bulb size. As bulb size had no effect on the initiation of sprouting, other factors such as storage temperature or sowing date may be the cause of sprouting. From this experiment, bulbs of late sown plants sprouted more than bulbs from early sown plants. This could be due to a shorter growth period of 186 days compared to 200 days of the earlier sown plants (Table 5.1), as previous studies have shown that natural growth inhibitors are transported from the leaves to the bulbs during bulb growth and maturation (Thomas, 1968; Hygrotech, 2010). A longer growth period available for the production and accumulation of growth inhibitors in the bulbs, resultied in a longer storage period without sprouting.

6.2.1.4 Bulb moisture loss

The percentage moisture lost from onion bulbs during storage was significantly influenced by the interaction between sowing date and storage type (Table 6.5). Bulbs harvested from plants sown on 25 May lost significantly less moisture (10.90%) when stored in the cold room than bulbs stored under room temperature conditions (25.17%). Interestingly, bulbs of early sown plants (11 May) stored under room temperature, did not lose as much moisture (11.33%) as bulbs stored in the cold room (18.54%).

Table 6.5: Percentage moisture loss of onion bulbs as influenced by sowing date and storage temperature in 2010

Storage (S)	Moisture loss (%) Sowing Date (SD)			Average (S)
	11 May	**25 May**	**8 June**	
Room	11.33	25.17	22.19	19.56
Cold Room	18.54	10.90	16.26	15.23
Average (SD)	14.94	18.04	19.23	
$LSD_{T(0.05)}$(SDxS)		**13.95**		

Cultivars also differed significantly in the percentage moisture lost during storage (Table 6.6). 'Ceres Gold' lost significantly less moisture than 'Python'. 'Charlize' and 'Jaquar' did not differ significantly from either 'Ceres Gold' or 'Python'.

Table 6.6: Percentage moisture loss of onion cultivars stored under room and cold room temperatures in 2010

Cultivar (C)	Moisture loss (%)
Charlize	15.71
Jaquar	20.26
Python	22.19
Ceres Gold	11.42
$LSD_{T(0.05)}$(C)	**10.21**

From this data moisture loss (10.90%) of bulbs harvested from plants sown on the 25 May and stored in the cold room were the closest to the percentage of moisture loss (10%) as seen acceptable during storage (Robinson *et al.*, 1975; Burton, 1982). Bulbs harvested from plants sown on 11 May and stored under room conditions were also only 11.33%. 'Ceres Gold' and 'Python' lost more moisture than 'Charlize' and 'Jaquar' and this corresponded with their neck diameter (Chapter 4, Section 4.2.2.3). 'Ceres Gold' and

'Python' recorded significantly thicker necks (18.96 and 13.81 mm, respectively) compared to 'Charlize' and 'Jaquar' (7.84 and 9.09 mm, respectively). Thamizharasi & Narasimham (1991) reported that moisture is mainly lost through the neck of the onion bulb during storage. The relative humidity was not controlled during the study and ranged between 48 and 50% in the room and 84 and 86% in the cold room. Both were outside the recommended humidity of 75% for onion storage. According to Brewster (2008), temperature and relative humidity influence moisture loss from the bulbs. Although a low temperature was maintained in combination with a high relatively humidity in the cold room, bulbs still lost a relative high percentage of moisture. The loss of moisture was also not attributed to bulb firmness.

6.2.2 Influence of sowing date and plant population on storage of 'Jaquar' bulbs

6.2.2.1 Storage duration

The storage duration of 'Jaquar' bulbs was not influenced by sowing date, plant population or storage conditions (Figure 6.4a-b). Interestingly, the number of storage days for 'Jaquar' bulbs for both field trials done in 2010 was 105 days (Chapter 6, Section 6.2.1.1, Figure 6.1c & d).

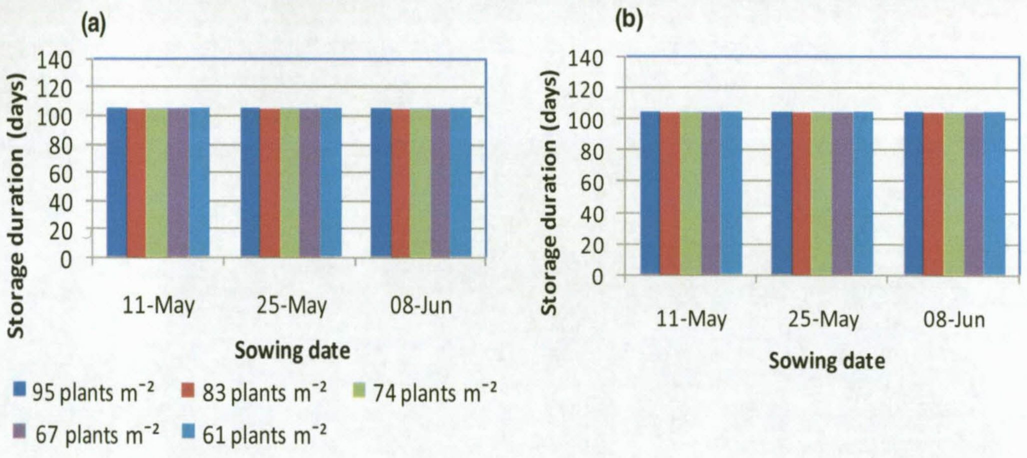


Figure 6.4: Storage duration of 'Jaquar' bulbs as influenced by sowing date, plant population and stored under (a) room or (b) cold room conditions during 2010

The storage period for 'Jaquar' was 105 days (3 months) under both storage conditions. This correspond with a storage potential of 2 to 3 months reported by Hygrotech (2009a), confirming that the genetic compositions of a cultivar will also determine its storability (Adamicki, 2005).

*6.2.2.2 **Black mould*** (*Aspergillus niger*)

Black mould infection of 'Jaquar' bulbs was affected by storage conditions but not sowing date or plant population (Table 6.7). All the 'Jaquar' bulbs stored under room temperature conditions were lost due to black mould which was first noticed after 15 weeks of storage but none were lost when stored in the cold room (Table 6.3).

Table 6.7: Number and total percentage bulb lost due to black mould (*A. niger*) of 'Jaquar' sown on different dates and at different plant populations during 2010 (n=33)

Storage	Sowing date	Plant population (plants m^{-2})	Storage period (weeks) 3	6	9	12	15	Total loss (%)
Room	11 May	95	0	0	0	0	33	100
		83	0	0	0	0	33	100
		74	0	0	0	0	33	100
		67	0	0	0	0	33	100
		61	0	0	0	0	33	100
	25 May	95	0	0	0	0	33	100
		83	0	0	0	0	33	100
		74	0	0	0	0	33	100
		67	0	0	0	0	33	100
		61	0	0	0	0	33	100
	8 June	95	0	0	0	0	33	100
		83	0	0	0	0	33	100
		74	0	0	0	0	33	100
		67	0	0	0	0	33	100
		61	0	0	0	0	33	100
Cold Room	11 May	95	0	0	0	0	0	0
		83	0	0	0	0	0	0
		74	0	0	0	0	0	0
		67	0	0	0	0	0	0
		61	0	0	0	0	0	0
	25 May	95	0	0	0	0	0	0
		83	0	0	0	0	0	0
		74	0	0	0	0	0	0
		67	0	0	0	0	0	0
		61	0	0	0	0	0	0
	8 June	95	0	0	0	0	0	0
		83	0	0	0	0	0	0
		74	0	0	0	0	0	0
		67	0	0	0	0	0	0
		61	0	0	0	0	0	0

The reason why bulb losses due to black mould were more for bulbs stored at room temperature (±25°C) than at cold room temperature (5°C) may be due to the fact that black mould infection occurs under warmer temperatures (24-30°C) while cooler conditions are not conducive for development of the disease (Sumner, 1995).

6.2.2.3 Sprouting

None of the 'Jaquar' bulbs sprouted when stored under room temperature conditions, irrespective of sowing date or plant population. Only bulbs harvested from plants sown on 25 May and stored in the cold room sprouted. Bulbs of plants that were sown at a lower plant population (61 or 74 plants m^{-2}) sprouted more (12.12%) than bulbs of plants planted at a higher plant population of 95 plants m^{-2} (9.09%) (Table 6.8).

Table 6.8: Number and total percentage of sprouted 'Jaquar' bulbs sown on different dates and plant population during 2010 (n=33)

Storage	Sowing date	Plant population (plants m^{-2})	Storage period (weeks) 3	6	9	12	15	Total lost (%)
Room	11 May	95	0	0	0	0	0	0.00
		83	0	0	0	0	0	0.00
		74	0	0	0	0	0	0.00
		67	0	0	0	0	0	0.00
		61	0	0	0	0	0	0.00
	25 May	95	0	0	0	0	0	0.00
		83	0	0	0	0	0	0.00
		74	0	0	0	0	0	0.00
		67	0	0	0	0	0	0.00
		61	0	0	0	0	0	0.00
	8 June	95	0	0	0	0	0	0.00
		83	0	0	0	0	0	0.00
		74	0	0	0	0	0	0.00
		67	0	0	0	0	0	0.00
		61	0	0	0	0	0	0.00
Cold Room	11 May	95	0	0	0	0	0	0.00
		83	0	0	0	0	0	0.00
		74	0	0	0	0	0	0.00
		67	0	0	0	0	0	0.00
		61	0	0	0	0	0	0.00
	25 May	95	0	0	0	3	0	9.09
		83	0	0	0	0	0	0.00
		74	0	0	1	3	0	12.12
		67	0	0	0	0	0	0.00
		61	0	0	1	3	0	12.12
	8 June	95	0	0	0	0	0	0.00
		83	0	0	0	0	0	0.00
		74	0	0	0	0	0	0.00
		67	0	0	0	0	0	0.00
		61	0	0	0	0	0	0.00

Bulbs of onions sown on 25 May at low plant populations of 61 or 67 plants m^{-2} recorded larger bulbs (59.57 and 64.05 mm, respectively) compared to bulbs of plants sown at higher populations of 95 or 83 plants m^{-2} (40.55 and 44.59 mm, respectively). Large onion bulbs contain low dry matter and it has been reported that high dry matter content prolong dormancy due to more growth regulators it contain (Ward, 1979; Chung, 1989; Sorensen & Grevsen, 2001; Tarpaga *et al.,* 2011). Comparing results of this experiment with those reported earlier in Chapter 6, Section 6.2.1.3 Table 6.4, 'Jaquar' is more prone to sprouting and bulbs stored at 5°C sprouted irrespective of sowing date. Room temperature does not encourage sprouting because of temperatures above 25°C which stimulate growth inhibitors that inhibit sprouting (Miedema, 1994; Sorensen & Grevsen, 2001).

6.2.2.4 Bulb moisture loss

The percentage moisture loss of 'Jaquar' bulbs during storage was significantly influenced by only sowing date and plant population. 'Jaquar' bulbs harvested from plants sown early (11 May) lost significantly more moisture than bulbs of later sown plants (25 May or 8 June) (Table 6.9). As sowing date was delayed, moisture loss from the bulbs during storage also decreased, although not always significant.

Table 6.9: Percentage moisture loss during storage of onion bulbs as influenced by sowing date in 2010 (n=33)

Sowing date (SD)	Moisture loss (%)
11 May	23.84
25 May	15.06
8 June	13.20
$LSD_{T(0.05)}$ (SD)	**7.01**

'Jaquar' bulbs harvested from plants planted at a population of 95 plants m^{-2} lost significantly less moisture (9.83%) than bulbs of plants planted at a population of 61 or 67 plants m^{-2} (22.67% or 21.79%, respectively) (Table 6.10).

Table 6.10: Percentage moisture loss during storage of onion bulbs as influenced by plant population in 2010 (n=33)

Plant populations (plants ha^{-1}) (PP)	Moisture loss (%)
95	9.83
83	17.65
74	18.28
67	21.73
61	22.67
$LSD_{T(0.05)}$ (PP)	**10.60**

Bulb moisture loss decreased as plant population increased from 61 to 95 plants m^{-2}, although not always significant. The loss of bulb moisture decreased from 23.84% to 13.20% as sowing date was delayed (Table 6.9) and decreased from 22.67% to 9.83% as plant population increased (Table 6.10). As sowing date was delayed, neck and bulb diameter also declined (Chapter 5, Section 5.2.2, Table 5.6 & 5.7) together with also decreasing moisture loss from the bulbs. It was also observed that as plant population increased, bulb and neck diameter decreased (Chapter 5, Section 5.2.2.3, Table 5.7) and percentage of moisture loss decreased (Table 6.10). This supports earlier reports that the amount of moisture loss from onion bulbs is influenced by the neck diameter and outer area of the bulbs (Thamizharasi & Narasimham, 1991).

6.3 SUMMARY AND CONCLUSIONS

Mid-intermediate day cultivars ('South Wester' and 'Ceres Gold') had a shorter storage life (2-3 months) than those of the short ('Charlize') or early intermediate ('Jaquar' and 'Python') day cultivars (3-4 months). 'South Wester' and 'Jaquar' were more susceptible to black mould than the other cultivars, with a higher rate of infection under room than cold room storage. During 2009 more bulbs of later sown onions (21 May) were infected with black mould due to the occurrence of rain prior to or during the harvesting period. Sprouting was more common in the intermediate day cultivars ('South Wester', 'Python' and 'Jaquar') than the short day cultivar Charlize when sown late. 'Python' and 'Jaquar' lost significantly more moisture under room storage than all the other cultivars.

Onions performed well under both storage conditions. It should however, be noted that black mould was more common at room temperatures while sprouting was more under cold room storage. Although sowing date did not have an impact on parameters measured, delayed sowing resulted in a high rate of black mould infection and sprouting.

Cultivars differ from each other with regard to their storability, susceptibility to black mould, sprouting and moisture loss. Although sowing date did not significantly influence bulb storability, black mould infection, sprouting and moisture loss were more common in bulbs from plants that were sown late. 'Charlize', 'Python' and 'Jaquar' bulbs could be stored for between three and four months, while those of 'South Wester' and 'Ceres Gold' only lasted for two to three months. Plant population did not influence bulb storage.

REFERENCES

ABBEY, L., DANQUAH, O.A., KANTON, R.A.L. & OLYMPIO., N.S., 2000. Characteristics and performance of eight onion cultivars. *Ghana J. Sci.* 40, 9-13.

ABD-ALLA, M.A., EL-MOHAMEDY, R.S.R. & BADEAA, R.I., 2006. Effect of some volatile compounds on black mould disease on onion bulbs during storage. *Res. J. Agric. Biol. Sci.* 2, 384-390.

ADAMICKI, F., 2005. Effects of pre-harvest treatments and storage conditions on quality and shelf life of onions. *Acta Hort.* 688, 229-238.

BENKEBLIA, N., VAROQUAUX, P., SHIOMI, N. & SAKAI, H., 2002. Storage technology of onion bulbs cv. Rouge Amposta: effects of irradiation, maleic hydrazide and carbamate isopropyl, N-phenyl (CIP) on respiration rate and carbohydrates. *Int. J. Food Sci. Tech.* 37, 169-175.

BISWAS, S.K., KHAIR, A., SARKER, P.K. & ALOM, M.S., 2010. Yield and storability of onion (*Allium cepa* L.) as affected by varying levels of irrigation. *Bangladesh J. Agric. Res.* 35, 247-255.

BREWSTER, J.L., 2008. Onions and other vegetable alliums. 2nd edn., CAB International, Wallingford, United Kingdom.

BURTON, W.G., 1982. Postharvest physiology of food crops. Longman, Inc., New York, United States of America.

CHUNG, B., 1989. Irrigation and bulb onion quality. *Acta Hort.* 247, 233-237.

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES, 2009. Statistics on fresh produce markets. Department of Agriculture, Report 47, Pretoria, South Africa.

FUSTOS, Z., GILINGER, M.P. & OMBODI, A., 1994. Effects of postharvest handling and cultivars on keeping quality of onions (*Allium cepa* L.) in storage. *Acta Hort.* 368, 212-219.

GAUTAM, I.P., KHATRI, B. & PAUDEL., G.P., 2006. Evaluation of different varieties of onion and their transplanting times for off-season production in mid hills of Nepal. *Nepal Agric. Res. J.* 7, 21-26.

GEARY, B., BECK, D. & THORNTON, M., 2006. Bulb to bulb transmission of *Botrytis allii* in dry bulb onion production. *HortScience* 41, 1064.

GREVSEN, K. & SORENSEN, J.N., 2004. Sprouting and yield in bulb onions (*Allium cepa* L.) as influenced by cultivar, plant establishment methods, maturity at harvest and storage conditions. *J. Hort. Sci. Biotechnol.* 79, 877-884.

GUBB, I.R. & MACTAVISH, H.S., 2002. Onion pre and postharvest considerations. *In*: H.D. Rabinowitch and L. Currah (eds.). Allium crop science: recent advances. CAB International, Wallingford, United Kingdom.

HANSEN, S.L., 1999. Content and composition of dry matter in onion (*Allium cepa* L.) as influenced by developmental stage at time of harvest and long term storage. *Acta Agric. Scand. Sect. B. Soil Plant Sci.* 49, 103-109.

HURST, W.C., SHEWFELT, R.L. & SCHULER, G.A., 1985. Shelf life and quality changes in summer storage onions (*Allium cepa* L.). *J. Food Sci.* 50, 761-763.

HYGROTECH, 2009a. Onion variety profiles: Short day length. Hygrotech Sustainable Solutions. www.hygrotech.com (Accessed 10/05/09).

HYGROTECH, 2009b. Onion variety profiles: Intermediate day length. Hygrotech Sustainable Solutions. www.hygrotech.com (Accessed 10/05/09).

HYGROTECH, 2010. Production guidelines of onions. Hygrotech Sustainable Solutions. Hygrotech, Pretoria, South Africa.

JILANI, M.S. & GHAFFOOR, A., 2003. Screening of local varieties of onion for bulb formation. *Int. J. Agric. Biol.* 5, 129-133.

KO, S.S., CHANG, W.N., WANG, J.F., CHERNG, S.J. & SHANMUGASUNDARAM, S., 2002. Storage variability among short day onion cultivars under high temperature and high relative humidity, and its relationship with disease incidence and bulb characteristics. *J. Amer. Soc. Hort. Sci.* 127, 848-854.

KOPSELL, D.A. & RANDLE, W.M., 1997. Short day onion cultivars differ in bulb selenium and sulphur accumulation which can affect bulb pungency. *Euphytica* 96, 835-390.

MALLOR, C., BALCELLS, M., MALLOR, F. & SALES, E., 2011. Genetic variation for bulb size, soluble solids content and pungency in Spanish sweet onion variety Fuentes de Ebro. Response to selection for low pungency. *Plant Breed.* 130, 55-59.

MIEDEMA, P., 1994. Bulb dormancy in onion. I. The effects of temperature and cultivar on sprouting and rooting. *J. Hort. Sci.* 69, 29-39.

MOHAN, S.K., 1995. Diseases caused by bacteria and a yeast: Soft rot. *In:* H.F. Schwartz & S.K. Mohan. (eds.). Compendium of onion and garlic diseases. APS Press, St Paul, Minnesota, United States of America.

MOHANTY, B.K. & PRUSTI, A.M., 2001. Performance of common onion varieties in Kharif seasons. *J. Trop. Agric.* 39, 21-23.

MOZUMDER, S.N., MONIRUZZAMAN, M. & HALIM, G.M.A., 2007. Effect of N, K and S on the yield and storability of transplanted onion (*Allium cepa* L.) in the Hilly Region. *J. Agric. Rural. Dev.* 5, 58-63.

MSUYA, D.G., REUBEN, S.O.W.M., MBILINYI, L.B., MAERERE, A.P., MSOGOYA, T., MULUNGU, L.S. & MISANGU, R.N., 2005. Evaluation of field performance and storage of some tropical short-day onion (*Allium cepa* L.) cultivars. *W. Afr. J. Ecol.* 8, 10-18.

NAM, E., CHO, D.Y., LEE, E.T., KIM, C.W., HAN, T., YOON, M.K. & KIM, S., 2011. Bulb storability of red and yellow onion (*Allium cepa* L.) cultivars grown in Korea. *Kor. J. Breed. Sci.* 43, 126-132.

PETERS, R.J., KOWITHAYAKORN, T., CHALARD, T. & RABINOWITCH, H.D., 1994. The effect of date of harvest on shelf life of onions stored by hanging from leaves. *Acta Hort.* 358, 365-368.

PRITHIVIRAJ, B., VIKRAM, A., KUSHALAPPA, A.C. & YAYLAYAN, V., 2004. Volatile metabolite profiling for the discrimination of onion bulbs infected by *Erwinia carotovora* ssp. *carotovora, Fusarium oxysporum* and *Botrytis allii. European J. Plant Pathol.* 110, 371-377.

RAJAPAKSE, R.G.A.S. & EDIRIMANNA, E.R.S.P., 2002. Management of bulb rot of big onion (*Allium cepa* L.) during storage using fungicides. *Ann. Sri Lanka Dept. Agric.* 4, 319-326.

RAMIN, A.A., 1999. Storage potential of bulb onions (*Allium cepa* L.) under high temperatures. *J. Hort. Sci. Biotechnol.* 74, 181-186.

ROBINSON, J.E., BROWNE, K.M. & BURTON, W.G., 1975. Storage characteristics of some vegetables and soft fruits. *Ann. Appl. Biol.* 81, 399-408.

RUTHERFORD, P.P. & WHITTLE, R., 1982. The carbohydrate composition of onions during long term cold storage. *J. Hort. Sci.* 57, 249-356.

SCHROEDER, B.K. & DU TOIT, L.J., 2010. Effects of postharvest onion curing parameters on enterobacter bulb decay in storage. *Plant Dis.* 94, 1425-1430.

SMITTLE, D.A., 1988. Evaluation of storage methods for 'Granex' onions. *J. Amer. Soc. Hort. Sci.* 113, 877-880.

SORENSEN, J.N. & GREVSEN, K., 2001. Sprouting in bulb onions (*Allium cepa* L.) as influenced by nitrogen and water stress. *J. Hort. Sci. Biotechnol.* 76, 501-506.

SORENSEN, J.N. & GREVSEN, K., 2002. Nitrogen and water stress affects sprouting in bulb onions stored over winter. *Acta Hort.* 571, 79-86.

SUMNER, D.R., 1995. Diseases of bulbs caused by fungi, black mold. *In:* H.F. Schwartz & S.K. Mohan. (eds.). Compendium of onion and garlic diseases. APS Press, St Paul, Minnesota, United States of America.

SUZUKI, M. & CUTCLIFFE, J.A., 1989. Fructans in bulbs onion in relation to storage life. *Can. J. Plant Sci.* 69. 1327-1333.

TARPAGA, M.V., ROUAMBA, A. & TAMINI, Z., 2011. Effects of the production season and the size of onion bulbs (*Allium cepa* L.) on their storage life at room temperature and humidity in Burkina Faso. *Agric. Biol. J. N. Am.* 2, 1072-1078.

THAMIZHARASI, V. & NARASIMHAM, P., 1991. Water vapour sorption and transmission by onion (*Allium cepa* L.) scale under different temperature and humidity conditions. *Sci. Hortic.* 46, 185-194.

THOMAS, T.H., 1968. The role of growth substances in the regulation of onion bulb dormancy. *J. Exp. Bot.* 20, 124-137.

TOLEDO, J., SHERMAN, M. & HUBER, D.J., 1984. Some effects of cultivar, bulb size and preharvest treatments on storage characteristics of North Florida onions. *Proc. Fla. State Hort. Soc.* 97, 106-108.

TYSON, J.L. & FULLERTON, R.A., 2004. Effect of soil borne inoculum on incidence of onion black mould (*Aspergillus niger*). *N. Z. Plant Prot.* 57, 138-141.

ULLAH, M.H., HUQ, S.M.I., ALAM, M.D.U. & RAHMAN, M.A., 2008. Impacts of sulphur levels on yield, storability and economic return of onion. *Bangladesh J. Agric. Res.* 33, 539-548.

WARD, C.M., 1979. The effect of bulb size on the storage life of onions. *Ann. Appl. Biol.* 91, 113-117.

WRIGHT, P.J. & GRANT, D.G., 1997. Effects of cultural practices at harvest on onion bulb quality and incidence of rots in storage. *N. Z. J. Crop Hort. Sci.* 25, 353-358.

YASIN, H.J. & BUFLER, G., 2007. Dormancy and sprouting in onion bulbs. I. Changes in carbohydrate metabolism. *J. Hort. Sci. Biotechnol.* 82, 89-96.

CHAPTER 7

SUMMARY AND RECOMMENDATIONS

7.1 SUMMARY

Three field trials and a storage trial were conducted. Two field trials were carried out to determine the effect of different sowing dates (30 April, 7 May, 21 May in 2009 and 11 May, 25 May, 8 June in 2010) on different cultivars ('Charlize', 'Jaquar', 'Python', 'South Wester' and 'Ceres Gold'). The third field trial in 2010 evaluated different plant populations (61, 67, 74, 83 and 95 plants m^{-2}) using one onion cultivar ('Jaquar'). The storage experiment was used to determine the effect of different storage temperatures (5°C and ±25°C) on onion bulbs.

7.1.1 Response of onion cultivars to different sowing dates

In this study it was observed that onion cultivars sown on different dates differed significantly regarding plant height but not leaf number. 'Python' plants grew more vigorously than of other cultivars. When sown late, shorter plants were produced. Cultivar did not significantly influence bulb fresh mass and yield, although, 'Jaquar' plants produced the heaviest bulbs and highest yield. When sowing was done from the end of April to mid May no significant difference in the fresh mass and yield was formed, but delaying sowing to the end of May to early June resulted in a significant decrease in bulb fresh mass and yield.

Bulb qualities of the different cultivars also vary, with plants of 'South Wester' and 'Ceres Gold' producing larger bulbs (82.51 and 60.06 mm, respectively) than those of other cultivars. Plants of these cultivars also produced bulbs with thicker necks (22.55 and 18.96 mm, respectively) than those of other cultivars, while 'Python' plants produced significantly firmer bulbs (59-74 mm) than the other cultivars (68.40-87.02 mm). Maximum bolting percentage occurred in 'South Wester' and 'Jaquar' plants sown on 30 April or 7 May significantly more than that noted in other cultivars at other planting dates. Best sowing date for all cultivars in Bloemfontein would, therefore, appear to be during May.

7.1.2 Response of onion (cv. Jaquar) to sowing date and plant population

Plant height was found to decrease as plant population increased, but leaf production was not significantly affected. Plant population also significantly influenced bulb fresh mass, although it did not have a significant influence on bulb yield. Although the difference was not significant, bulb yield reached a peak at a plant population of 74 plants m^{-2} and decreased with a further increase in plant population. Both bulb fresh mass and yield decreased significantly as sowing date was delayed. Neck diameter, bulb firmness, bolting and bulb shape were all significantly influenced by plant population, with bulb and neck sizes decreasing with increasing plant population, and firmer bulbs being produced as plant population decreased.

It was evident that plant population influenced growth, bulb yield and quality. A plant population of 74 plants m^{-2} sown during May gave the best results.

7.1.3 Storage of onion bulbs as influenced by plant population and sowing date

Mid intermediate cultivars had a shorter shelf life (2-3 months) than the short or early-intermediate day cultivars (3-4 months). Factors such as disease infection, sprouting and moisture loss were associated with cultivar as well as storage conditions. The duration of the plants growth period also played a role in bulb storage. The longer the growth period, associated with early sowing, the longer the storage period attained.

It was evident that plant population did not influence bulb storage. Bulbs from plants planted at a density of 61 and 74 plants m^{-2} were susceptible to black mould, sprouting and moisture loss. Black mould and sprouting were more associated with storage conditions than plant population. Sprouting only occurred when sowing was done on 25 May. Moisture loss decreased as sowing was delayed.

When considering all the storage results, it is clear that cultivars differed from each other regarding shelf life, susceptibility to black mould, sprouting and moisture loss. High black mould infections, sprouting and moisture loss occurred when sowing was delayed to end of May.

7.2 RECOMMENDATIONS

- The cultivar 'Jaquar' can be recommended for planting in this area since it out performed all the other cultivars in both seasons, although cultivars did not differ significantly in yield, which is the primary objective of any producer.
- The best sowing date in the Bloemfontein area is from the end of April to the end of May for all the cultivars studied, as this result in the best vegetative growth and yield. This date is however, not suitable for cultivars that are susceptible to bolting.
- A plant population of 74 plants m^{-2} is recommended for higher yields and a high percentage of medium sized bulbs. However, for the production of extra small (10-34 mm) and small (35-39 mm) plant population of 83-95 plants m^{-2} is recommended and between 67 and 61 plants m^{-2} for large bulbs (70-89 mm).

7.3 SCOPE FOR FUTURE RESEARCH

- More field experiments should be carried out to determine the planting date, with planting taking place at seven day intervals commencing from April to the end of May.
- Different maturity at harvesting should be considered when evaluating the storage of onions in the future research.
- An important relationship exist between temperature and relative humidity during storage and different combinations of these two factors should be considered in future research.

Appendix 1

Table 1: Daily weather information for 2009 and 2010 season (South African Astronomical Observatory, 2009 & 2010; Department of Metrological Services, 2010; Weather Underground, 2010)

	2009															
	January				February				March				April			
Day	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain
	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)
1	30.8	16.2	13.58	5.8	29.4	18.1	13.26	0.0	28.3	15.0	12.41	0.0	28.3	15.3	11.46	0.0
2	30.4	14.7	13.57	18.8	29.1	18.1	13.25	0.0	26.7	15.9	12.39	0.0	28.2	14.4	11.44	0.5
3	29.7	14.3	13.57	1.0	31.4	18.0	13.23	0.0	27.8	15.5	12.37	4.8	26.8	13.8	11.43	0.0
4	29.8	11.9	13.56	0.3	30.2	15.0	13.22	0.0	27.9	13.9	12.35	0.0	26.4	14.1	11.41	0.0
5	32.4	13.8	13.56	0.0	26.4	14.7	13.20	4.6	27.1	14.4	12.34	0.0	26.7	13.6	11.39	0.5
6	33.6	15.9	13.55	1.8	29.2	16.2	13.19	0.0	27.4	15.0	12.32	0.0	27.5	12.8	11.37	0.0
7	35.1	13.7	13.55	0.0	29.2	17.3	13.17	11.4	27.9	14.8	12.30	0.0	27.8	12.6	11.36	0.0
8	34.1	20.7	13.54	0.0	28.8	16.8	13.16	0.3	27.9	12.8	12.28	0.0	25.9	13.8	11.34	0.0
9	32.3	20.1	13.53	0.3	29.1	17.2	13.14	2.5	27.7	16.2	12.27	9.1	25.6	11.7	11.32	0.0
10	28.8	18.7	13.52	0.3	27.9	17.5	13.13	0.5	26.0	14.5	12.25	0.0	27.2	10.7	11.31	0.0
11	32.0	17.7	13.51	22.9	23.6	16.6	13.11	2.5	27.6	14.6	12.23	0.0	27.4	13.7	11.29	0.0
12	27.7	17.1	13.50	5.8	16.7	14.1	13.09	6.6	26.9	15.0	12.21	0.0	28.3	8.1	11.27	0.0
13	28.7	16.9	13.49	0.0	20.0	14.0	13.08	9.4	23.7	16.2	12.20	1.5	26.2	10.0	11.26	0.0
14	32.8	19.3	13.48	0.0	24.9	16.1	13.06	8.4	24.8	14.7	12.18	3.3	27.1	8.4	11.24	0.0
15	31.6	19.3	13.47	0.0	24.3	13.8	13.04	30.2	25.8	15.1	12.16	0.0	27.5	8.7	11.22	0.0
16	33.8	21.3	13.46	0.0	25.5	10.4	13.03	0.0	26.8	13.9	12.14	0.0	27.6	9.3	11.21	0.0
17	34.8	19.7	13.45	0.0	30.4	10.7	13.01	0.0	25.3	12.2	12.12	0.0	27.3	11.7	11.19	0.0
18	33.9	17.1	13.44	0.0	28.7	15.7	13.00	0.0	25.2	8.5	12.11	0.0	25.9	13.3	11.18	0.0
19	33.1	17.3	13.43	0.0	24.8	17.7	12.58	1.3	23.8	12.2	12.09	0.0	26.4	9.2	11.16	0.0
20	33.3	16.7	13.42	0.0	27.7	18.3	12.56	2.5	24.3	10.2	12.07	0.0	23.6	8.3	11.14	0.0
21	32.3	17.3	13.41	0.0	26.6	18.1	12.54	0.0	26.4	6.0	12.05	0.0	21.1	8.1	11.13	0.0
22	27.6	16.4	13.40	0.0	23.5	17.2	12.53	0.8	26.9	7.8	12.04	0.0	21.1	9.6	11.11	0.0
23	28.7	13.0	13.38	0.0	25.6	16.6	12.51	0.3	28.4	10.8	12.02	0.0	19.8	10.8	11.10	0.0
24	31.4	13.5	13.37	0.0	25.5	16.0	12.49	0.0	28.2	11.2	12.00	0.5	22.3	12.8	11.08	5.6
25	32.2	16.1	13.36	16.3	26.1	16.3	12.48	0.3	28.7	15.0	11.58	0.0	21.6	10.4	11.07	2.0
26	21.2	17.1	13.35	2.0	28.1	17.5	12.46	8.9	29.3	13.9	11.56	0.0	17.1	5.7	11.05	0.0
27	25.1	16.3	13.33	0.8	26.7	17.2	12.44	6.9	29.6	13.9	11.55	0.0	21.4	3.5	11.04	0.0
28	19.0	14.7	13.32	33.8	27.3	17.0	12.42	0.5	30.1	17.3	11.53	0.0	24.0	4.1	11.02	0.0
29	22.5	14.8	13.30	5.1					28.8	17.3	11.51	2.0	23.8	9.4	11.01	0.0
30	29.4	15.9	13.29	0.0					28.1	16.0	11.49	0.0	19.2	9.0	10.59	3.3
31	30.7	17.0	13.28	0.0					28.9	11.7	11.48	0.0				

Temp = Temperature, Max = Maximum, Min = Minimum, and Photo = Photoperiod

Table 1: Continued

Day	2009															
	May				June				July				August			
	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain
	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)
1	19.3	3.7	10.58	0.0	16.3	0.8	10.23	0.0	15.8	12.0	10.18	0.0	9.4	6.6	10.44	8.4
2	20.7	5.8	10.56	0.0	19.3	0.3	10.22	0.0	15.2	11.7	10.19	0.0	17.3	5.4	10.46	0.3
3	21.6	7.9	10.55	2.0	18.2	0.1	10.22	0.0	16.3	11.4	10.19	0.0	18.7	3.1	10.47	0.0
4	21.9	11.1	10.53	6.1	18.3	3.8	10.21	0.0	15.9	10.6	10.19	0.0	19.5	2.7	10.48	0.0
5	19.4	10.8	10.52	8.4	19.4	1.1	10.21	0.0	14.2	9.9	10.20	0.0	21.1	7.9	10.50	0.0
6	21.3	9.8	10.51	0.0	18.9	6.3	10.20	0.0	15.7	11.1	10.20	0.0	21.3	2.4	10.51	0.0
7	21.0	7.8	10.49	0.3	16.7	6.7	10.20	0.0	17.9	10.3	10.21	0.0	21.9	4.1	10.52	0.0
8	19.6	7.4	10.48	0.0	12.2	6.5	10.19	0.0	17.4	10.1	10.22	0.0	22.3	8.4	10.54	0.0
9	19.5	6.7	10.47	0.0	16.7	5.2	10.19	0.0	17.4	9.8	10.22	0.0	21.8	7.9	10.55	0.0
10	19.5	7.2	10.45	0.0	11.2	8.0	10.18	6.6	17.8	10.1	10.23	0.0	23.3	6.9	10.56	0.0
11	20.4	5.6	10.44	0.0	14.3	9.1	10.18	1.5	19.3	7.4	10.24	0.0	24.6	7.2	10.58	0.0
12	22.3	5.8	10.43	0.0	17.2	6.4	10.18	0.0	12.4	10.3	10.24	0.5	22.2	4.6	10.59	0.0
13	21.3	8.4	10.42	0.0	19.6	6.3	10.17	8.6	15.3	11.4	10.25	0.3	13.2	1.3	11.01	0.0
14	21.0	6.9	10.40	0.0	15.8	3.4	10.17	1.3	9.7	13.3	10.26	0.0	18.9	0.7	11.02	0.0
15	21.2	9.9	10.39	2.5	20.6	2.3	10.17	0.0	10.4	13.7	10.27	0.0	20.7	2.1	11.04	0.0
16	21.2	9.1	10.38	1.3	18.8	9.2	10.17	0.3	14.8	13.6	10.27	0.0	21.6	4.6	11.05	0.0
17	11.6	3.0	10.37	0.0	19.7	6.3	10.16	0.0	18.1	11.9	10.28	0.0	18.8	8.8	11.07	0.0
18	17.6	1.2	10.36	0.0	20.9	5.0	10.16	0.0	17.4	10.6	10.29	0.0	20.4	7.7	11.08	0.0
19	21.1	1.8	10.35	0.0	19.2	6.4	10.16	0.3	18.2	10.9	10.30	0.0	13.2	1.6	11.10	0.0
20	21.7	3.6	10.34	0.0	16.7	6.5	10.16	0.0	17.3	9.7	10.31	0.0	13.5	0.7	11.11	0.0
21	19.7	7.7	10.33	0.0	19.0	10.2	10.16	0.0	17.2	10.7	10.32	0.0	17.3	-2.3	11.13	0.0
22	21.6	8.1	10.32	0.0	19.6	8.9	10.16	8.6	16.8	10.1	10.33	0.0	20.3	-0.6	11.14	0.0
23	21.8	9.0	10.31	0.0	11.7	6.0	10.16	0.0	9.6	12.7	10.34	0.0	20.8	4.1	11.16	0.0
24	21.4	6.8	10.30	0.0	10.3	0.6	10.16	0.3	10.9	14.3	10.35	0.0	21.2	3.9	11.17	0.0
25	21.8	6.9	10.29	0.0	10.4	-0.4	10.17	0.0	14.1	13.6	10.36	0.0	22.9	7.1	11.19	0.0
26	22.1	3.1	10.28	0.0	8.7	-1.6	10.17	0.0	17.8	11.9	10.37	0.0	23.8	8.2	11.21	0.0
27	21.2	3.0	10.27	0.0	15.0	0.3	10.17	0.0	18.1	10.7	10.38	0.0	19.6	5.8	11.22	1.0
28	22.1	2.7	10.26	0.0	14.7	-1.8	10.17	0.0	16.8	9.3	10.40	0.0	21.0	0.8	11.24	0.0
29	19.4	3.0	10.25	0.0	17.1	1.1	10.17	0.0	18.1	8.6	10.41	0.0	24.6	4.9	11.25	0.0
30	11.6	-0.5	10.25	0.0	15.0	2.3	18.18	0.0	17.9	7.5	10.42	0.0	26.5	11.9	11.27	0.0
31	14.1	-2.3	10.24	0.0					13.3	9.2	10.43	10.2	27.9	10.4	11.29	0.0

Table 1: Continued

	2009															
	September				October				November				December			
Day	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain
	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)
1	28.6	10.5	11.30	0.0	25.9	13.2	12.22	5.8	24.7	12.6	13.14	7.1	31.5	13.9	13.51	0.0
2	25.3	10.4	11.32	0.0	25.2	11.1	12.24	5.1	23.2	12.3	13.15	0.0	31.3	15.7	13.52	0.0
3	24.1	5.2	11.34	0.0	23.1	12.8	12.25	2.0	25.7	13.3	13.17	0.0	31.2	13.0	13.53	0.0
4	27.4	3.5	11.35	0.0	21.1	12.8	12.27	6.1	20.1	12.1	13.19	17.0	32.4	12.3	13.54	0.0
5	28.7	10.5	11.37	0.0	23.9	11.5	12.29	0.0	26.3	10.6	13.20	0.3	32.8	15.0	13.54	0.0
6	28.7	11.7	11.39	0.0	28.2	10.7	12.30	0.3	28.7	10.1	13.22	0.0	32.7	16.9	13.55	10.9
7	29.1	14.0	11.40	0.0	28.1	14.4	12.32	0.0	28.9	16.4	13.23	9.1	31.1	16.1	13.56	0.5
8	20.8	8.7	11.42	0.0	25.2	6.3	12.34	0.0	28.7	16.4	13.24	6.1	28.6	16.8	13.56	10.9
9	20.1	4.1	11.44	0.0	27.8	5.6	12.36	0.0	21.7	10.6	13.26	3.3	27.9	16.3	13.57	7.4
10	20.2	8.8	11.45	0.0	30.1	8.8	12.27	0.0	21.8	7.1	13.27	0.0	30.3	14.9	13.57	0.0
11	18.6	4.1	11.47	0.0	20.0	14.1	12.39	11.7	25.6	8.6	13.29	0.0	29.2	15.3	13.58	0.0
12	23.8	2.1	11.49	0.0	18.6	9.9	12.41	15.5	29.7	11.3	13.30	0.0	31.8	16.0	13.58	0.0
13	26.6	10.2	11.51	0.0	21.7	5.1	12.43	0.0	27.8	15.2	13.31	0.0	33.0	16.0	13.59	0.0
14	27.6	6.2	11.52	0.0	27.3	9.6	12.44	0.0	25.3	9.3	13.33	0.0	25.9	15.4	13.59	21.8
15	26.7	12.7	11.54	0.0	27.1	15.1	12.46	0.0	24.9	9.1	13.34	0.0	31.5	15.0	13.59	0.0
16	23.5	11.5	11.56	0.0	23.9	14.8	12.46	2.8	26.1	10.3	13.35	0.0	29.6	14.1	14.00	0.0
17	23.8	9.8	11.57	0.0	26.1	13.7	12.48	0.3	20.9	9.9	13.37	0.0	32.7	11.9	14.00	0.0
18	19.0	6.3	11.59	0.0	24.9	9.8	12.49	0.0	19.6	9.7	13.38	37.8	32.9	13.9	14.00	0.0
19	22.8	0.4	12.01	0.0	25.4	8.7	12.51	0.0	22.4	8.7	13.39	0.0	33.9	15.2	14.00	0.0
20	24.4	5.3	12.03	0.0	27.0	10.7	12.53	0.0	18.8	8.7	13.40	4.3	34.1	16.6	14.00	0.0
21	26.4	9.4	12.04	0.0	31.0	12.7	12.56	0.0	19.9	11.7	13.41	0.0	32.9	18.6	14.00	2.0
22	27.8	7.3	12.06	0.0	31.3	14.4	12.58	0.0	26.5	10.1	13.43	0.0	34.5	17.2	14.00	0.0
23	26.7	11.3	12.08	0.0	31.0	15.7	12.59	0.0	29.6	12.9	13.44	0.0	31.4	20.2	14.00	0.8
24	28.7	8.9	12.10	0.0	30.2	15.7	13.01	1.5	29.2	17.0	13.45	0.0	33.9	17.3	14.00	0.0
25	25.7	8.8	12.11	0.0	23.9	14.9	13.03	2.3	30.7	17.5	13.46	0.0	34.2	17.5	14.00	0.0
26	28.1	8.2	12.13	0.0	25.1	14.8	13.04	0.8	32.4	15.8	13.47	0.0	32.2	17.9	14.00	0.0
27	29.9	9.8	12.15	0.0	25.1	15.2	13.06	0.0	30.4	14.1	13.48	0.0	31.2	14.6	14.00	0.0
28	25.7	8.6	12.17	0.0	25.7	14.3	13.08	7.1	31.4	13.6	13.49	0.0	33.7	14.8	13.59	0.0
29	19.8	10.7	12.18	0.0	23.8	12.4	13.09	0.0	32.1	19.7	13.50	0.0	32.0	13.9	13.59	0.0
30	20.8	10.8	12.20	0.0	25.1	8.3	13.11	0.0	30.4	17.7	13.51	0.0	34.3	15.4	13.59	0.0
31					24.4	12.7	13.12	9.4					34.2	18.2	13.58	0.0

Table 1: Continued

	2010															
	January				February				March				April			
Day	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain
	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)
1	30.2	18.4	13.58	0.3	28.0	15.3	13.27	0.3	28.7	16.5	12.41	0.0	23.7	15.1	11.46	0.0
2	19.9	16.4	13.57	13.2	29.7	13.2	13.25	0.0	29.6	15.8	12.39	4.3	26.8	13.6	11.45	0.0
3	28.8	17.1	13.57	0.0	29.9	16.3	13.24	1.0	28.2	15.9	12.38	0.0	26.9	13.2	11.43	0.0
4	30.3	17.5	13.56	1.8	30.0	13.5	13.22	0.3	26.7	16.9	12.36	2.5	27.2	13.7	11.41	13.2
5	29.1	15.2	13.56	0.0	29.9	17.3	13.21	0.0	27.8	16.6	12.34	1.0	24.4	13.9	11.40	18.1
6	29.4	16.0	13.55	0.0	30.3	16.0	13.19	0.0	30.2	16.0	12.32	0.0	23.1	14.2	11.38	0.0
7	30.1	20.7	13.54	0.0	31.4	17.4	13.18	0.0	28.9	16.8	12.31	0.0	24.6	12.2	11.36	0.0
8	29.3	16.0	13.54	13.5	31.9	18.2	13.16	1.5	28.7	15.4	12.29	0.0	25.5	8.7	11.34	0.0
9	30.7	17.0	13.53	11.4	30.6	17.3	13.15	0.0	29.1	14.7	12.27	0.0	26.7	11.6	11.33	0.0
10	26.6	17.8	13.52	0.8	30.1	20.6	13.13	0.0	30.7	16.1	12.25	0.0	23.8	10.1	11.31	0.0
11	24.2	15.6	13.51	1.8	30.1	19.0	13.11	0.3	31.2	16.2	12.23	0.0	26.1	8.3	11.29	0.0
12	27.6	16.4	13.50	0.3	32.5	18.8	13.10	1.3	31.6	15.3	12.22	0.0	27.1	10.7	11.28	0.0
13	28.6	17.2	13.50	0.0	33.6	20.7	13.08	0.0	29.3	17.6	12.20	1.0	28.6	10.1	11.26	0.0
14	29.0	16.9	13.49	3.6	32.2	18.9	13.07	0.0	29.4	15.7	12.18	0.0	28.0	11.5	11.24	0.0
15	31.4	22.9	13.48	0.0	29.0	16.4	13.05	27.2	28.5	15.7	12.16	0.0	27.2	10.8	11.23	0.0
16	31.2	16.1	13.47	0.0	24.6	15.9	13.03	13.2	28.5	13.3	12.15	0.0	20.7	14.2	11.21	1.0
17	33.7	16.5	13.46	0.0	26.4	15.4	13.02	0.0	25.9	13.9	12.13	3.0	24.3	13.5	11.20	0.5
18	32.9	19.6	13.44	0.8	28.8	14.6	13.00	0.0	27.2	13.9	12.11	0.0	24.3	12.9	11.18	1.3
19	22.7	16.9	13.43	16.3	29.8	14.6	12.58	0.0	29.1	12.7	12.09	0.0	22.2	12.1	11.16	9.1
20	26.1	16.8	13.42	0.0	29.7	18.2	12.57	0.0	28.2	15.1	12.08	1.5	19.0	4.8	11.15	0.0
21	24.6	16.9	13.41	2.8	30.4	17.6	12.55	0.0	27.3	14.1	12.06	0.0	20.6	6.2	11.13	0.0
22	19.7	16.8	13.40	9.9	29.2	18.6	12.53	0.0	28.2	14.2	12.04	4.6	20.1	7.3	11.12	0.0
23	25.8	16.3	13.39	2.5	28.1	17.7	12.51	3.0	26.9	13.8	12.02	2.0	19.2	4.7	11.10	0.0
24	29.3	16.9	13.37	0.0	18.2	15.0	12.50	71.9	27.2	14.2	12.01	0.0	19.2	7.3	11.09	0.5
25	26.7	16.9	13.36	17.8	26.6	15.5	12.48	4.8	25.9	16.0	11.59	23.4	20.0	9.3	11.07	0.0
26	20.8	16.7	13.35	14.0	26.3	15.0	12.46	0.0	24.2	16.8	11.57	19.8	17.6	8.5	11.05	0.3
27	29.8	16.1	13.34	0.0	28.	15.2	12.45	0.0	22.4	10.4	11.55	8.4	14.7	9.8	11.04	2.0
28	30.9	16.5	13.32	0.0	28.6	16.2	12.43	0.0	24.1	6.3	11.53	0.0	17.9	11.6	11.02	1.8
29	29.9	15.8	13.31	0.0					27.2	9.2	11.52	0.0	21.8	8.7	11.01	0.0
30	27.9	17.1	13.29	0.0					27.8	15.6	11.50	6.1	17.6	8.7	11.00	0.0
31	27.0	17.3	13.28	2.2					21.9	16.2	11.48	0.0				

Table 1: Continued

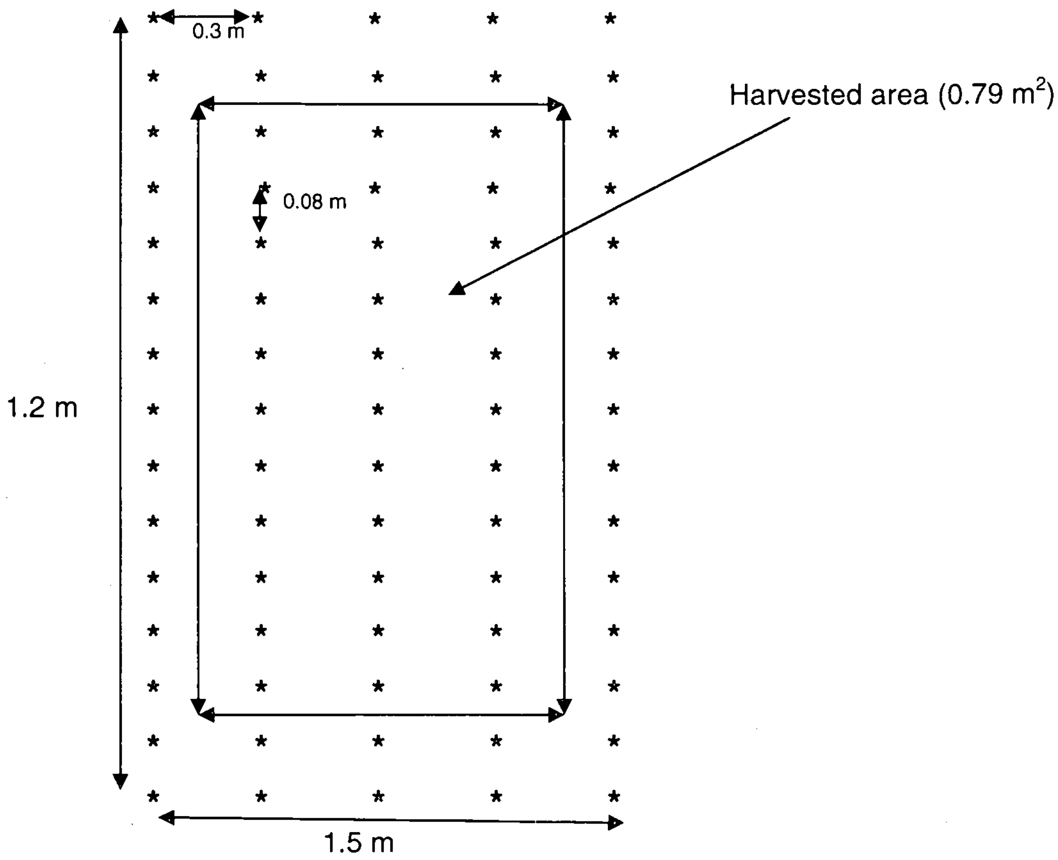
Day	2010															
	May				June				July				August			
	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain	Temp (°C)		Photo	Rain
	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)	Max	Min	(hours)	(mm)
1	23.4	12.2	10.58	8.1	18.3	1.9	10.23	0.0	19.5	5.1	10.18	0.0	20.6	4.4	10.44	0.0
2	22.0	11.4	10.57	0.0	18.6	0.9	10.23	0.0	18.7	5.0	10.18	0.0	21.5	4.5	10.45	0.0
3	17.0	11.8	10.55	28.2	17.3	-0.6	10.22	0.0	17.9	10.3	10.19	0.0	22.1	3.4	10.47	0.0
4	20.9	9.7	10.54	0.3	18.9	4.2	10.21	0.0	18.8	7.3	10.19	0.0	21.3	48.	10.48	0.0
5	18.6	5.0	10.52	0.0	18.7	1.3	10.21	0.0	16.2	7.8	10.20	0.0	21.4	4.2	10.49	0.0
6	20.2	4.4	10.51	0.0	21.7	0.4	10.20	0.0	20.4	4.4	10.20	0.0	22.1	3.8	10.51	0.0
7	21.8	4.8	10.50	0.0	23.3	2.4	10.20	0.0	21.8	8.3	10.21	0.0	21.2	7.2	10.52	0.0
8	25.9	8.8	10.48	0.0	17.6	7.1	10.29	0.0	17.9	7.2	10.21	0.0	23.8	7.7	10.53	0.0
9	25.1	10.4	10.47	0.5	13.8	2.5	10.19	0.0	16.7	7.3	10.22	0.0	11.4	2.6	10.55	0.0
10	17.9	5.4	10.46	0.0	9.2	1.9	10.18	5.8	19.9	8.0	10.23	0.0	14.2	-0.3	10.56	0.0
11	15.6	5.1	10.44	0.0	17.2	8.1	10.18	14.0	12.4	2.3	10.23	0.0	16.0	3.1	10.58	0.0
12	18.6	1.9	10.43	0.0	18.8	6.0	10.18	0.3	10.4	-03.	10.24	0.0	15.7	2.2	10.59	0.0
13	24.1	5.2	10.42	0.0	15.9	2.5	10.17	0.0	13.1	-1.3	10.25	0.0	18.7	-0.8	11.00	0.0
14	24.2	12.1	10.41	0.0	16.4	1.3	10.17	0.0	15.3	4.7	10.26	0.0	21.3	-0.1	11.02	0.0
15	16.7	9.8	10.40	1.0	7.5	-1.1	10.17	0.0	10.5	1.9	10.26	0.0	21.8	0.9	11.03	0.0
16	21.4	10.8	10.38	1.8	7.1	-4.1	10.17	0.0	11.8	-0.6	10.27	0.0	25.2	0.8	11.05	0.0
17	22.4	9.3	10.37	0.0	12.2	-1.1	10.17	0.0	18.6	-2.5	10.28	0.0	23.2	7.2	11.06	0.0
18	22.3	7.1	10.36	0.0	14.3	-1.4	10.16	0.0	19.7	0.9	10.29	0.0	25.2	5.6	11.08	0.0
19	23.2	6.4	10.35	0.0	14.2	-1.5	10.16	0.0	19.9	-0.6	10.30	0.0	18.2	3.0	11.08	0.0
20	22.6	5.7	10.34	0.0	16.9	-1.6	10.16	0.0	21.2	-0.1	10.31	0.0	18.9	-1.0	11.11	0.0
21	22.1	5.9	10.33	0.0	18.2	-0.7	10.16	0.0	20.1	0.9	10.32	0.0	21.7	5.4	11.12	0.0
22	21.9	4.9	10.32	0.0	18.5	0.6	10.16	0.0	19.1	4.2	10.33	0.0	25.5	5.6	11.14	0.0
23	22.2	4.5	10.31	0.0	14.9	-0.7	10.16	0.0	20.3	1.9	10.34	0.0	14.9	0.2	11.16	0.0
24	22.1	3.6	10.30	0.0	17.8	-2.9	10.16	0.0	20.4	6.7	10.35	0.0	20.3	-1.1	11.17	0.0
25	22.4	4.7	10.29	0.0	22.1	-1.2	10.17	0.0	21.7	6.0	10.36	0.0	21.9	9.3	11.19	0.0
26	22.6	7.2	10.28	0.0	22.4	-0.6	10.17	0.0	22.2	4.2	10.37	0.3	21.2	5.7	11.20	0.0
27	21.4	10.0	10.27	0.0	22.7	2.0	10.17	0.0	22.8	3.9	10.38	0.0	20.2	-0.7	11.22	0.0
28	13.6	0.9	10.26	0.0	17.4	7.7	10.17	0.0	23.9	4.4	10.49	0.0	26.9	3.1	11.23	0.0
29	16.7	-0.4	10.26	0.0	17.9	9.1	10.17	0.0	23.1	4.3	10.40	0.0	28.4	5.3	11.25	0.0
30	17.9	2.1	10.25	0.0	18.9	6.7	10.18	0.0	18.2	8.4	10.42	0.0	26.5	11.8	11.27	0.0
31	16.3	4.7	10.24	0.0					19.1	5.1	10.43	0.0	26.1	11.3	11.28	0.0

Table 1: Continued

Day	2010															
	September				October				November				December			
	Temp (°C)		Photo (hours)	Rain (mm)	Temp (°C)		Photo (hours)	Rain (mm)	Temp (°C)		Photo (hours)	Rain (mm)	Temp (°C)		Photo (hours)	Rain (mm)
	Max	Min			Max	Min			Max	Min			Max	Min		
1	28.2	12.1	11.30	0.3	30.2	16.3	12.21	0.0	31.9	15.0	13.14	0.0	32.1	16.6	13.51	0.0
2	24.3	9.9	11.32	0.0	31.3	13.8	12.23	0.0	32.2	16.4	13.15	0.5	29.1	16.3	13.52	1.0
3	23.0	2.2	11.33	0.0	31.6	14.5	12.25	0.0	29.7	16.5	13.17	2.0	26.3	14.1	12.53	9.9
4	26.7	1.6	11.35	0.0	30.4	8.8	12.27	0.0	27.7	13.8	13.18	0.0	27.4	8.9	13.54	0.0
5	28.8	5.2	11.37	0.0	28.9	15.4	12.28	0.3	28.9	13.3	13.20	0.0	28.4	11.5	13.54	0.0
6	29.1	7.7	11.38	0.0	32.4	17.4	12.30	0.0	28.6	9.9	13.21	0.0	27.6	12.6	13.55	0.0
7	25.6	8.3	11.40	0.0	30.4	15.8	12.32	0.5	30.8	10.2	13.23	0.0	29.8	12.8	13.56	0.0
8	28.3	8.9	11.42	0.0	28.9	11.8	12.34	0.0	32.3	16.2	13.24	10.4	31.9	15.5	13.56	0.0
9	20.6	12.3	11.43	0.0	30.8	7.5	12.35	0.0	17.2	15.1	13.26	2.0	32.9	15.5	13.57	1.0
10	42.2	6.4	11.45	0.0	31.1	9.9	12.37	0.0	21.0	9.0	13.27	0.0	32.1	16.9	13.57	0.3
11	25.6	4.7	11.47	0.0	24.5	9.6	12.39	0.0	28.0	8.0	13.28	0.0	29.5	17.2	13.58	0.0
12	27.8	7.2	11.48	0.0	24.7	7.1	12.40	0.0	27.0	8.0	13.30	0.0	27.2	13.6	13.58	7.9
13	29.1	9.0	11.50	0.0	21.3	14.3	12.42	8.6	31.0	6.0	13.31	0.0	24.8	13.4	13.59	2.0
14	29.2	10.4	11.52	0.0	19.9	7.3	12.44	0.0	32.0	10.0	13.32	0.0	27.3	14.2	13.59	10.7
15	29.5	15.2	11.54	0.0	18.3	7.1	12.46	0.0	29.0	14.0	13.34	0.0	19.2	14.1	13.59	9.1
16	25.5	10.6	11.55	0.0	21.7	6.0	12.47	0.0	25.0	14.0	13.35	15.0	26.6	16.0	14.00	4.8
17	28.3	13.0	11.57	0.0	25.3	9.1	12.49	0.0	26.0	12.0	13.36	0.0	28.6	11.9	14.00	0.0
18	26.1	13.3	11.59	0.0	28.3	11.4	12.51	0.0	24.0	13.0	13.38	23.0	31.5	15.7	14.00	0.0
19	28.3	16.5	12.00	0.0	27.8	11.3	12.52	0.0	27.0	12.0	13.39	0.0	29.2	16.7	14.00	0.0
20	25.2	16.5	12.02	0.0	30.4	7.0	12.54	0.0	31.0	12.0	13.40	0.0	27.6	14.0	14.00	0.0
21	17.1	7.6	12.04	0.0	30.2	9.6	12.56	0.0	31.0	15.0	13.41	5.0	21.8	13.4	14.00	32.8
22	21.4	2.3	12.06	0.0	25.9	13.6	12.57	1.0	31.6	18.9	13.42	1.5	31.3	14.3	14.00	0.0
23	27.7	3.4	12.07	0.0	25.5	13.9	12.59	6.6	29.9	16.6	13.43	0.3	31.0	15.8	14.00	0.0
24	30.9	9.4	12.09	0.0	26.8	13.4	13.01	3.6	29.5	16.4	13.45	0.0	30.0	11.4	14.00	0.0
25	30.8	11.4	12.11	0.0	20.6	5.6	13.02	0.0	25.1	14.3	13.46	0.0	29.2	13.8	14.00	0.0
26	29.4	15.0	12.13	0.0	23.5	6.7	13.04	0.0	28.1	14.3	13.47	6.6	29.8	15.3	14.00	0.0
27	22.1	8.4	12.14	0.0	27.2	11.9	13.06	0.0	28.8	15.0	13.48	6.9	31.3	16.8	14.00	6.3
28	23.3	5.0	12.16	0.0	23.9	9.7	13.07	0.0	31.6	16.2	13.49	0.0	32.6	15.9	13.59	2.3
29	25.3	11.1	12.18	0.0	26.5	10.1	13.09	0.0	28.4	12.9	13.50	0.0	26.6	18.2	13.59	3.3
30	29.2	9.7	12.20	0.0	30.6	8.8	13.10	0.0	30.1	13.8	13.50	0.0	27.5	16.0	13.59	3.8
31					31.3	15.0	13.12	0.0					23.7	15.8	13.58	17.8

Day	January 2011			
	Temp (°C)		Photo (hours)	Rain (mm)
	Max	Min		
1	22.0	16.0	13.55	19.0
2	25.0	15.0	13.55	7.0
3	24.0	17.0	13.54	21.0
4	25.0	16.0	13.53	3.0
5	28.0	17.0	13.53	1.0

ppendix 2



igure 1: Plot layout indicating number of plants and the harvested area during 2009

Appendix 2: continued

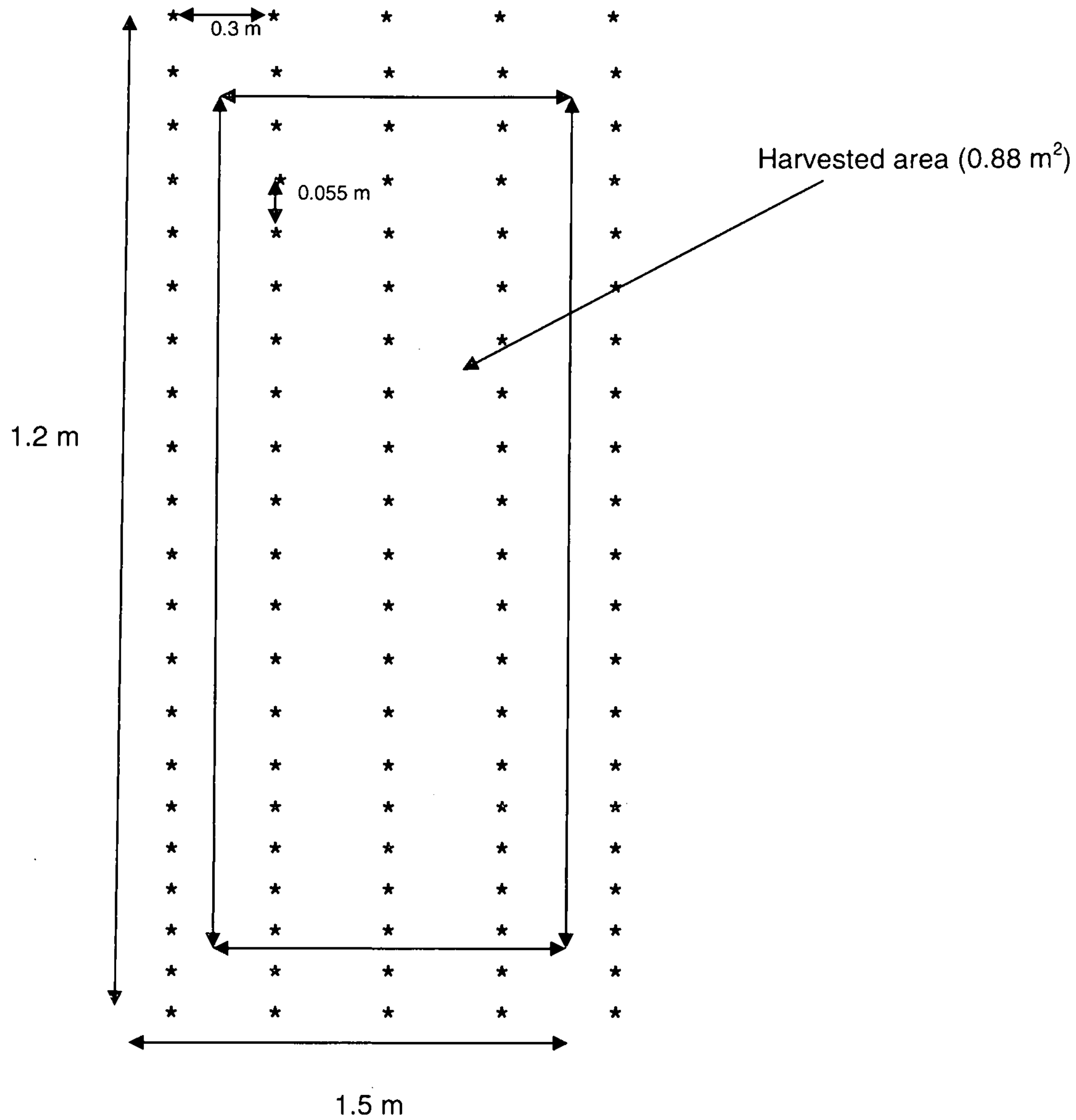
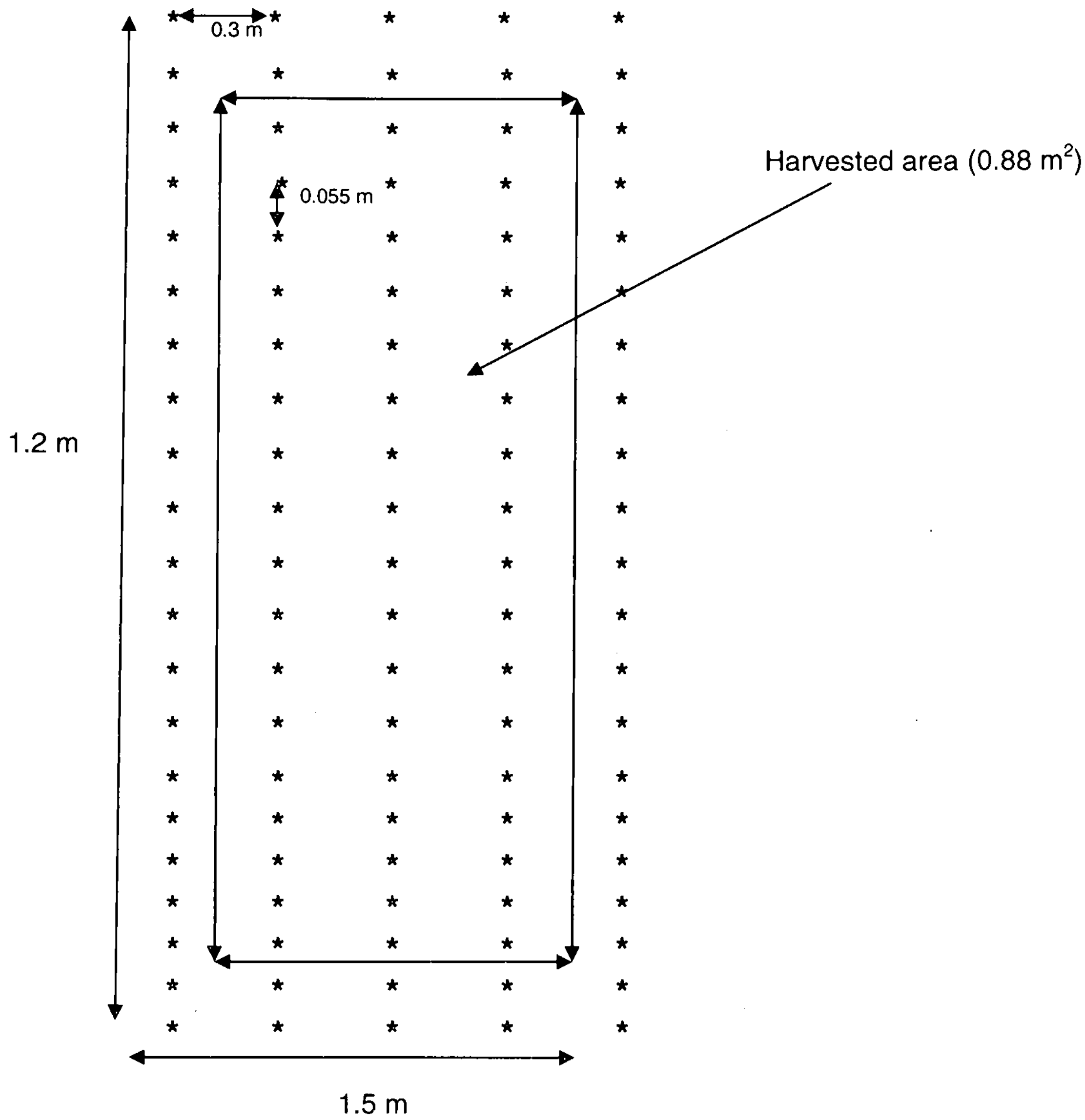


Figure 2: Plot layout indicating number of plants and the harvested area during 2010

ppendix 2: continued



igure 3a: Plot layout for a plant population of 61 plants m^{-2}, indicating number of plants and the harvested area during 2010

ppendix 2: continued

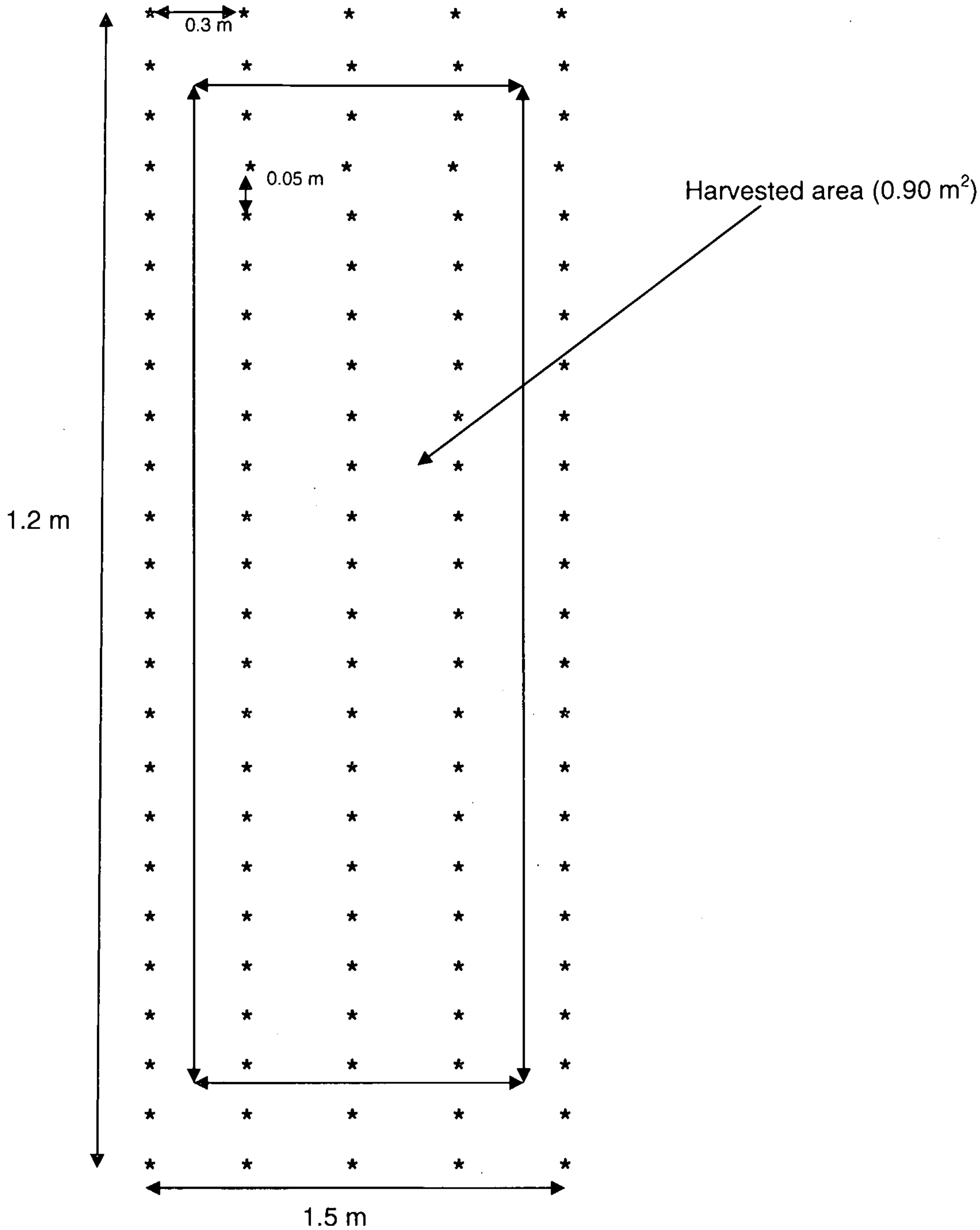
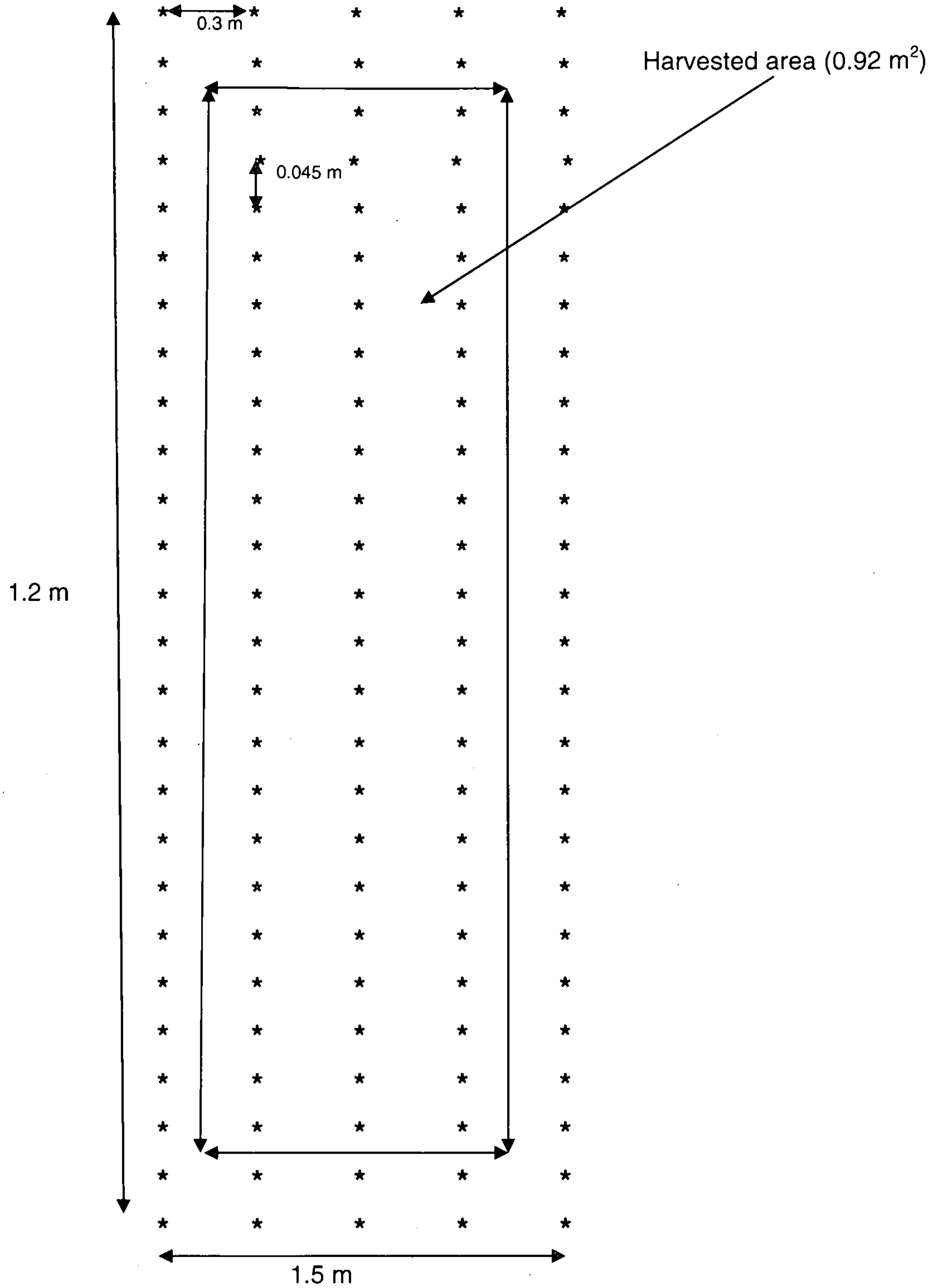


Figure 3b: Plot layout for a plant population of 67 plants m^{-2}, indicating number of plants and the harvested area during 2010

ppendix 2: continued



igure 3c: Plot layout for a plant population of 74 plants m^{-2} indicating number of plants and the harvested area during 2010

Appendix 2: continued

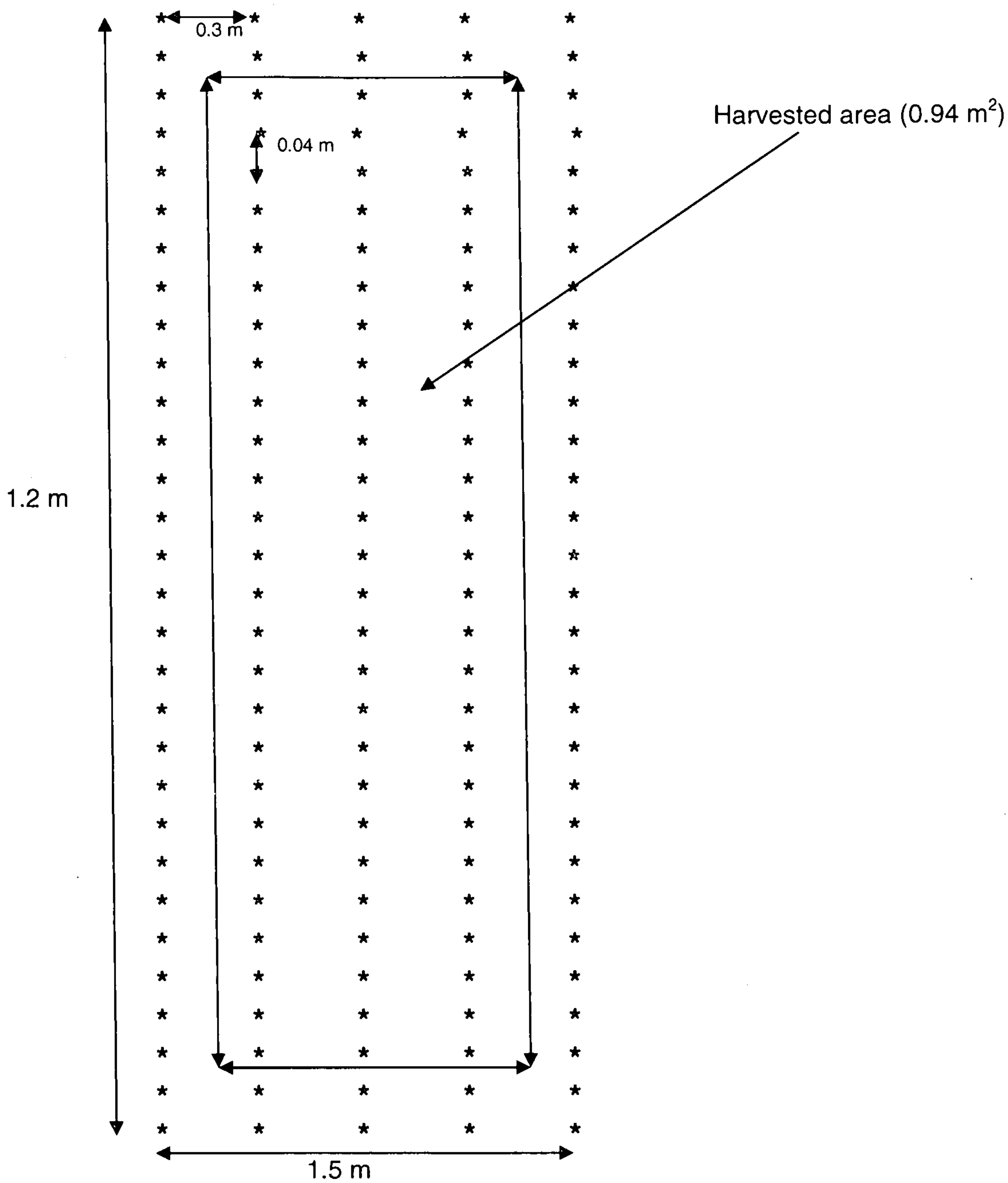


Figure 3d: Plot layout for a plant population of 83 plants m^{-2} indicating number of plants and the harvested area during 2010

Appendix 2: continued

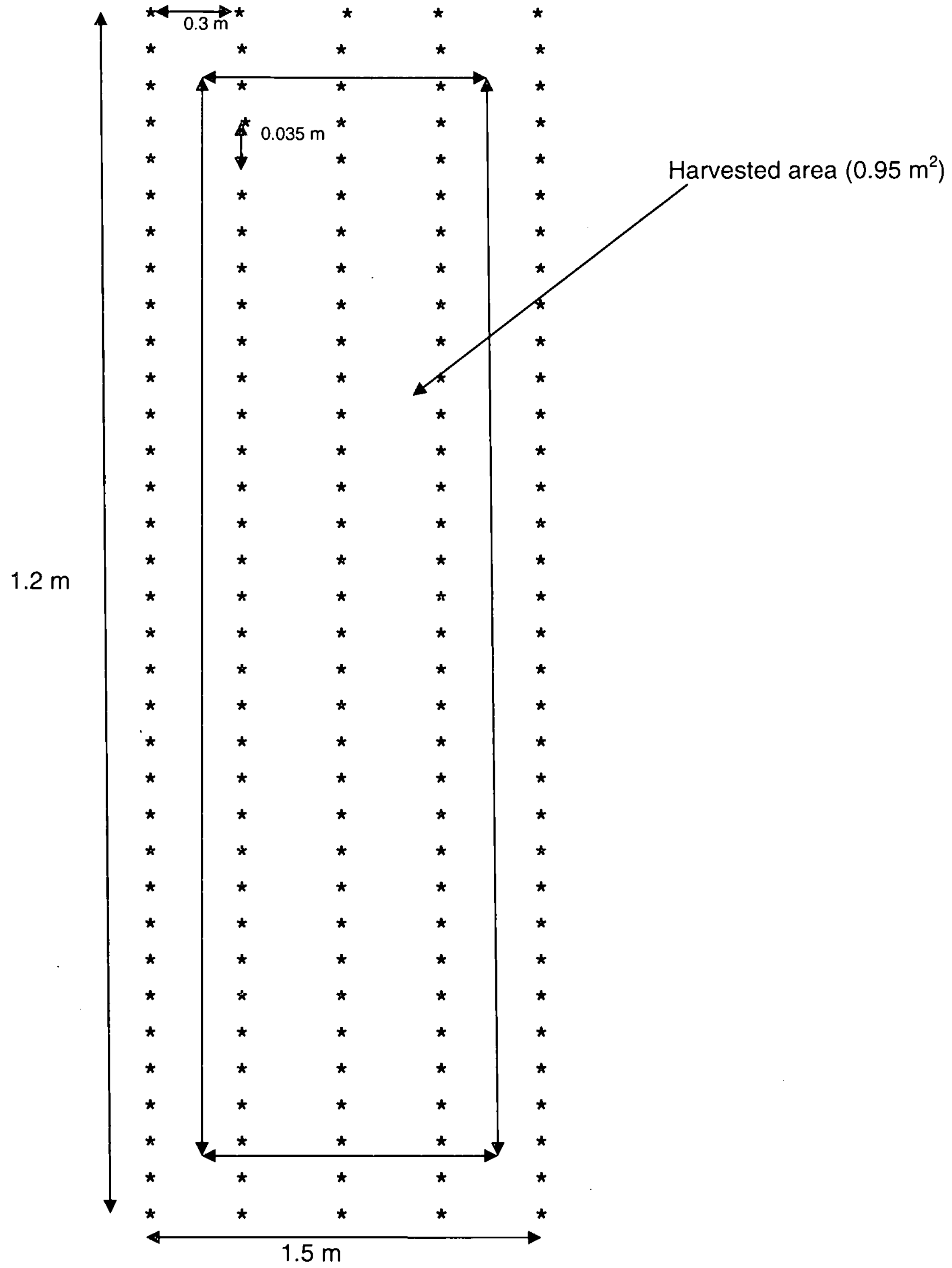


Figure 3e: Plot layout for a plant population of 95 plants m^{-2} indicating number of plants and the harvested area during 2010