UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Effect of planting dates and densities on yield and yield components of short and ultra-short growth period maize (*Zea mays L.*)

By

Hans Kgasago

Submitted in compliance with the requirements for the degree

M. Inst. Agrar: Agronomy

In the Faculty of Natural and Agricultural Sciences
Department of Plant Production and Soil Science
University of Pretoria

Supervisor: Prof. C.F. Reinhardt
Co-Supervisor: Dr. J.M. Steyn
Mentor: Dr. S. Maali

October 2006

DECLARATION

I hereby declare that this thesis, prepared for the degree M. Inst. Agrar, which was submitted by me to the University of Pretoria, is my own work and has not been submitted to any other university.

I also agree that the University of Pretoria has the sole right to publication of this thesis.

Signed: ____

Hans Kgasago

TABLE OF CONTENTS

CHAPTER 1: LITERATURE REVIEW

CHAPTER 2: GENERAL MATERIAL AND METHODS

CHAPTER 3: EFFECT OF PLANTING DATE, PLANT DENSITY AND CULTIVAR ON VEGETATIVE GROWTH OF FIVE SHORT AND ULTRA-SHORT GROWTH CULTIVARS AT BETHLEHEM AND POTCHEFSTROOM

CHAPTER 4: EFFECT OF PLANTING DATE, PLANT DENSITY AND CULTIVARS ON YIELD AND YIELD COMPONENTS OF SHORT AND ULTRA-SHORT GROWTH CULTIVARS AT BETHLEHEM AND POTCHEFSTROOM

CHAPTER 5: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

LIST OF ABBREVIATIONS

ARC	Agricultural Research Council
CV	Coefficient of variance
cm	Centimeter
g	Gram
ha	Hectare
ha^{-1}	Per hectare
K	Potassium
kg	Kilogram
KNC	Kernel number per cob
LAI	Leaf area index
m	Meter
m^{2}	Square metre
m^{-2}	Per square metre
ml	Millilitre
N	Nitrogen
Ns	Non significant
P	Phosphorous
PAR	Photosynthetic active radiation
RUE	Radiation use efficiency
SAS	Statistical Analysis System
%	Percentage

ACKNOWLEDGEMENTS

This study was conducted with the kind permission of the ARC-Grain Crops Institute. The following people deserve special recognition. Firstly I would like to thank my mentor Dr. S. Maali for her mentorship guidance and a continued encouragement throughout this study. My supervisor, Prof C.F. Reinhardt`s enthusiasm, humor and especially his patience throughout all the work is highly appreciated and treasured. I am also grateful to my co-supervisor Dr. J.M. Steyn for his valuable suggestion and advice in writing this thesis. I also acknowledge the financial support and funding for this study from Canon and National Research Foundation, which otherwise would not have been possible.

It would not have been possible to carry out this work alone and I am indebted to all my friends, colleques and fellow students who morally and physically helped me in the field and in laboratory work. I would also like to extend a very special thanks to my fiancé and best friend Rebotile for her moral support during my studies and her great assistance in entering the data, whenever I needed it most. Roselinah Masindeni also deserves special thanks for her continued support from the start until the end. I would also like to thank my parents, brothers, sisters and relatives for their continued love, support and encouragement who in one way or another helped in fulfillment of this work. Finally, I would like to thank the Almighty God for giving me life, strength and courage, otherwise the work would not have been possible.

ABSTRACT

Effect of planting dates and densities on yield and yield components of short and ultra-short growth period maize (*Zea mays L.*)

by

Hans Kgasago

Supervisor: Prof. C.F. Reinhardt

Co-Supervisor: Dr. J.M. Steyn

Mentor: Dr. S. Maali

Degree: M. Inst. Agrar: Agronomy

In general, yield reduction in most dryland maize growing areas of South Africa occur because seasonal rainfall distribution is erratic with annual variation that cannot be predicted accurately. Cultivar selection, planting date and plant density are other factors that consistently affect maize yield. Long growing season maize cultivars are higher yielding, particularly under conditions of good moisture and nutrient supply. However, as both moisture and nutrient availability becomes more limiting, yield tends to decline. Short growing season maize cultivars could yield more than long season counterparts because they can maximize the growing season and potentially reach the critical flowering stage before traditional midsummer droughts occur. The short growing season maize cultivars, which have only recently been developed, have traits, which can address the problem of reduced yield, which is ascribed to midsummer drought. There has been no previous effort to evaluate the effects of planting dates and plant densities on yield and yield components of these short and ultra-short growth period maize cultivars. This prompted research in the 2004/05 growing season. One field experiment was conducted at each of two selected areas (Bethlehem & Potchefstroom) in the "Maize Triangle" of South Africa. The aim was to evaluate the response of short and ultra-short growth period maize cultivars to planting dates and plant densities at two localities with distinct environmental conditions. The effects of planting date, plant density and cultivar on yield and yield components were investigated. Both yield and yield components were affected by planting date, plant density and cultivar at both localities. At both localities early and optimum planting dates as well as low and optimum plant densities promoted increases in yield components, which contributed to increased grain yield. As for the cultivars, PAN6017 proved to be the most consistent since it out-performed other cultivars in terms of both vegetative growth, yield components and grain yield at both localities. At both localities, plant height, leaf area index and dry matter yield were affected by both planting date and plant density, with optimum planting date and optimum plant density contributing to highest yield components and yield. PAN 6017 was superior to the other cultivars at all planting dates and plant densities at both localities. In order to make findings from a study such as this applicable to the "Maize Triangle", more research on short and ultra-short growth period maize cultivars should be conducted over a wider range of locations and seasons.

Keywords: Cultivars, cob number, dry matter, grain yield, kernel number per cob, leaf area index, planting date, plant density, 100 seed mass.

INTRODUCTION

Maize (*Zea mays L*) is the world's most widely grown cereal and it is ranked third among major cereal crops (Ayisi & Poswall, 1997). In the developed countries, maize is grown mainly for animal feed and used as raw materials for industrial products such as starch, glucose and dextrose (FAO, 1999). However, on the African continent, it is the most dominant food crop and mainstay of rural diets, mainly in the eastern and southern regions. In South Africa, maize is considered the main staple food and the most extensively grown field crop, followed by wheat, sugar cane, sorghum and other minor crops (Ayisi & Poswall, 1997).

South African maize farmers annually plant approximately 3.7 million hectares and of this area, 3.5 million hectares are cultivated under dryland conditions with expected mean yield of 2.5 ton ha^{-1}. About 0.19 million hectares of maize are under irrigation with an expected average yield of about 8.5 ton ha^{-1} (Agric Stat, 2004). Dryland production mainly takes place in the Free State (34%), North West (32%), Mpumalanga (24%) and KwaZulu-Natal (3%) Provinces (Agric Stat, 2004). Dryland maize production in South Africa varies considerably from year to year, depending on the amount and distribution of rainfall. A mixture of dry spells and erratic rainfall, with annual variation that cannot be predicted accurately, consistently have negative impact on the growth and yield of maize (Benhil, 2002). Additionally, traditional midsummer drought towards the end of January aggravates the problem, particularly in the Northern Maize Triangle (Mpumalanga, North West and Free State), although all maize production areas are prone to drought during this time of the year. Generally, yield reduction in most dryland maize growing areas occur because seasonal rainfall distribution is erratic (Du Toit *et al*., 2002). Undoubtedly, water availability, specifically the lack thereof is the most pressing and significant factor limiting the production of dryland maize in South Africa (PECAD, 2003).

Successful maize production requires an understanding of various management practices as well as environmental conditions that affect crop performance (Eckert, 1995). Selection of appropriate cultivars, planting dates and plant densities are cultural practices that have been shown to affect maize yield potential and stability

(Norwood, 2001). Cultivar selection should be based on adaptation to growing environments coupled with good return. Since producers worldwide indicated that dryland maize production began to increase in the early 1990s, the perception has been that it should be planted early so that it can be pollinated before high midsummer temperatures occur (Norwood, 2001). Therefore, short growing season hybrids stand a better chance to overcome this problem because they can mature quickly before traditional mid-summer drought begins (Cross, 1990; Franzky, 1996; Lewis, 1998). This is of utmost importance because excessive heat during flowering can inhibit pollination, which result in yield reduction (ARC-GCI, 2002). Drought occurring at flowering can lead to greater yield losses than when it occurs at other developmental stages (Grant *et al.*, 1989). Water deficits lasting only one or two days during tasselling or pollination may cause as much as 22% reduction in yield (Hall *et al.*, 1981).

Plant density is considered one of the most important crop management practices and is accorded a high research priority (Sangoi *et al.*, 2002). Plant density affects yield by influencing yield components such as number of ears, number of kernels per ear, and kernel mass (Ahmadi *et al.*, 1993). The ideal plant number per area depends on several factors such as water availability, soil fertility, hybrid maturity and row spacing (Staggenborg *et al.*, 1999; Argenta *et al.*, 2001). Under optimum water and nutrient supply, high plant density can result in an increased number of cobs per unit area**,** with eventual increase in grain yield (Bavec & Bavec, 2002). Larson & Clegg (1999) also reported that full growing season hybrids could produce high yield at a high plant density under optimum water and nutrient supply. Unlike full season hybrids, short growing season (early) hybrids might improve yield stability, especially during adverse years because growth is nearer to completion before the traditional mid-summer drought begins (Norwood, 2001).

In general, maize grown in short season areas has less leaf area than maize grown in long season areas, largely because of small plant stature accompanied by decreased leaf number and size (Modarres *et al.*, 1998). However, Hunter (1977) was able to increase both leaf area and grain yield of short season cultivars by simply increasing plant population. Moreover, Troyer (1968) found that the smaller, earlier maturing maize varieties tended to withstand crowding better than the larger, later maturing varieties. Thus, high plant density and uniform plant distribution within the row tended to compensate for the smaller plant size and lower yield per plant of the early maturing varieties (Alessi & Power, 1975).

Planting date was reported to affect the growth and yield of maize significantly. To date, the challenge for maize growers is finding the narrow window between planting too early and planting too late (Nielson, 1997; Nielson *et al*., 2002). Farmers who plant maize early are concerned about frost, poor emergence and early plant growth. On the other hand, farmers who plant late wonder what maturity hybrids to plant and how late planting might affect the final grain yield and grain moisture (Lauer *et al*., 1999). Either early planting or late planting can result in lower yield because the probability exists that unfavorable climatic conditions can occur after planting or during the growing season. Norwood (2001) suggested that farmers should plant on more than one planting date in order to safeguard against unpredicted seasons.

Short season hybrids can be planted early without detrimental effects on their maximum yield potential. It can also minimize the risk of obtaining immature cobs and grains or sustaining early frost damage (Hicks *et al*., 1993). It also provides the opportunity for replanting if the first crop failed. The early maturing hybrids can be planted as much as three to four weeks after full season hybrids, and be harvested about three weeks earlier (Hicks *et al*., 1993).

The vulnerability of maize to adverse climatic change has become an important issue and therefore, a research priority. What should be done to mitigate the effects of uncertain weather and erratic rainfall remains a challenge and question to researchers and farmers countrywide. Therefore, the overall objective of this study was to investigate the beneficial effects of growing short and ultra-short maize cultivars under different production environments in the drier central parts of South Africa.
The specific objectives were the following:
(a) To assess the influence of plant density and planting date on the performance of short and ultra-short maize hybrids**,** as well as on an ultra-short open-pollinated variety.
(b) To study the performance of these hybrids and the variety under different growing conditions.

(c) To assess the introduction of ultra-short open-pollinated varieties to low potential areas, which might be suitable and important to developing farmers.

References

ABSTRACT OF AGRICULTURAL STATISTICS., 2004. National Department of Agriculture. Pp. 7-9. Pretoria.

AHMADI, M., WIEBOLD, W.J., BEUERLEIN, J.E., ECKERT, D.J. & SCHOPER, J., 1993. Agronomic practices that affect corn kernel characteristics. *Agron. J.* 85, 615-619.

ALESSI, J. & POWER, J.F., 1975. Response of an early maturing maize hybrid to planting date and plant population in the Northern Plains. *Agron. J.* 67, 762-765.

ARC-GCI, 2002., Maize information guide. ARC-Grain Crop Institute, Potchefstroom, South Africa. Pp. 31-38.

ARGENTA, G., SILVA, P.R.F. & SANGOI, L., 2001. Arranjo de plantas emmilho: analise do estado da arte. *Ci. Rur.* 31, 1075-1084.

AYISI, K.K. & POSWALL, M.A.T., 1997. Grain yield potential of maize and dry bean in a strip intercropping system. *Appl. Plant Sci.* 11, 56-59.

BAVEC, F. & BAVEC, M., 2002. Effect of plant population on leaf area index, cob characteristics and grain yield of early maturing maize cultivars. *Europ. J. Agron.*16, 151-159.

BENHIL, J. 2002., Climate, water and agriculture: Impacts on and adaptation of agro-ecological systems in South Africa. A case study of the Republic of South Africa. University of Pretoria, South Africa.

CROSS, H.Z., 1990. Selecting for rapid leaf expansion in early maturing maize. *Crop Sci.* 30, 1029-1032.

DU TOIT, A.S., PRINSLOO, M.A., DURAND, W. & KIKER, G., 2002. Vulnerability of maize production to climate change and adaptation in South Africa, Combined Congress: South African Society of Crop Protection and South African Society of Horticultural Science, Pietermaritsburg (SA).

ECKERT, D., 1995. Corn production in Ohio. *http://ohioline.osu.edu/b472/. htm*

Food and Agricultural Organization (FAO)., 1999. Yearbook of maize production. Vol. 45. FAO, Rome, Italy. Pp. 265.

FRANZKY, K., 1996. Farmers should plant balance varieties to ensure success. *www.garstseed.com*

GRANT, R.F., JACKSON, B.S., KINIRY J.R. & ARKIN, G.F., 1989. Water deficits timing effects on yield components in maize. *Agron. J.* 81, 61-65.

HALL, A.J., LEMCROFT, J.H. & TRAPANI, N., 1981. Water stress before and during flowering in maize and its effects on yields, its components and their determinants. *Maydica*. 26, 19-38.

HICKS, D.R., HARRINGTON, J.D. & MCGAHEN, J.H., 1993. Maximizing the advantages of early corn planting. National Corn Handbook, Crop Management. Purdue University Cooperative Extension Service. West Lafayette, Indiana. NCH-35.

HUNTER, R.B., 1977. Growing corn and sorghum in short-season areas. In proc. Thirty-second Annu. Corn and Sorghum Res. Conf., Am. Seed Trade Assoc. Washington, D.C.

LARSON, E.J. & CLEGG, M.D., 1999. Using corn maturity to maintain grain yield in the presence of late season drought. *J. Prod. Agric*. 12, 400-405.

LAUER, J.G., CARTER, P.R. WOOD, T.M., DIEZEL, G., WIERSMA, D.W., RAND, R.E. & MLYNAREK, M.J., 1999. Corn hybrid response to planting date in the Northern Corn Belt. *Agron. J*. 91, 834-839.

LEWIS, B., 1998. Corn hybrid selection. Pioneer Hi-Bred International, Inc. CCA, American Society of Agronomy. Pp. 53-65.

MODARRES, A.M., HAMILTON, R.I., DIJAK, M., DWYER, L.M., D.W. STEWART, D.W. & SMITH, D.L., 1998. Plant population density effects of maize inbred lines grown in short season environments. *Crop Sci*. 38,104-108.

NIELSON, R.L., THOMISON, P.R., BROWN, G.A., HALTER, A.L., WELLS, J. & WUETHRICH, K.L., 2002. Delayed planting date effects on flowering and grain maturation of corn. *Agron. J*. 94, 549-558.

NIELSON, N.J. 1997., An early planted corn. *http://www.landecago.com/ehprefgd.pdf*

NORWOOD, C.A. 2001. Dryland corn production in Western Kansas: Effect of hybrid maturity, planting date and plant population. *Agron. J*. 93, 540-547.

PECAD., 2003. Production Estimates and Crop Assessment Division. South African Corn Production. *http://www.fas.usda.gov/pecad2/highlights/2001/02/SAfrica/02.htm*

SANGOI, L., GRACIETTI, M.A., RAMPAZZO, C. & BIACHETTI, P., 2002. Response of Brazilian maize hybrids from different eras to changes in plant population. *Field Crops Res*. 79, 39-51.

STAGGENBORG, S.A., FJELL., D.L., DELVIN, D.L., GORDON, W.B., MADDUX, L.D. & MARSH, B.H., 1999. Selecting optimum planting dates and plant population for dryland corn production. *J. Prod. Agric*. 12, 85-90.

TROYER, A.F., 1968. Yield as influenced by maturity and population. Proc. Annu. Hybrid Corn Sorghum Res. Conf. AM. Seed Trade Assoc. 22, 91-98.

CHAPTER 1: LITERATURE REVIEW

The most important goal in any farming system is to minimize risk, maximize productivity and make profit. In general, the low productivity of dryland maize could be attributed to a combination of factors including low soil fertility, drought, low temperatures, erratic rainfall and deficient soil moisture during the growing season (Major *et al.*, 1991). Of all these factors, erratic rainfall and drought are perhaps the more difficult phenomena to manage, primarily because their occurrences are unpredictable (Du Toit *et al.*, 2002). They are more detrimental during the flowering, grain formation and filling stages of maize, which result in severe yield losses (ARC-GCI, 2002). Therefore, to achieve profitable maize production, growers need to apply the most advanced management practices, including balanced soil fertility, adequate weed control, timely planting, optimum plant density and selection of maize hybrids that can take advantage of these practices (Norwood, 2001). Thus, varieties suitable for dryland production areas should perform well under both favourable and unfavourable conditions.

1.1. Planting density effects

1.1.1. General background

Plant density per unit area is an important agronomic practice for the production of maize. Plant density that is too low result in unnecessary sacrificing of yield, but over-estimating the required density also lead to unnecessary stress on the plants, which in turn has a detrimental effect on yield (ARC-GCI, 1999). Row widths under dryland conditions also play an important role in determining plant density. Intra-row spacing should not be too narrow as this can increase competition between plants to such an extent that yield is detrimentally affected. It is, however, just as important to maintain an even stand in the row as maintaining total plant density. It should also be noted that an interaction exists between cultivars and plant density, as not all cultivars react the same to an increase in plant density. However, where the environment does not limit yield, the rule applies that higher plant densities result in higher yield (ARC-GCI, 2002). In such situation, the higher density will produce smaller ears or fewer kernels per plant, but the greater number of plants will still result in a higher yield. Target yield plays an important role in determining the required plant density for each maize producing area. In cooler producing areas, plant densities ranging from 16000 to

37000 plants ha^{-1} are ideal for yield targets in the range of two to six tons per hectare. In warmer producing areas, plant densities ranging from 10000 to 28000 plants ha^{-1} are ideal for yield targets ranging from two to six tons per hectare, whereas plant densities of 12000 to 31000 ha^{-1} are recommended in temperate producing areas (ARC-GCI, 1999, 2002).

Maize producers continually search for methods that will help them to increase yields, reduce costs, or a combination of both. Plant distribution in the field as affected by plant density and or row spacing has been one area that has received a great deal of attention over the last several decades (Farnham, 2001). Westgate *et al*., (1997) reported that average grain yield of maize has increased steadily in recent years. Among other agricultural management practices, increased plant density and decreased row spacing have both contributed to increased grain yield per unit area (Westgate *et al*., 1997).

1.1.2. Grain yield

Maize grain yield can be described as a function of the rate and duration of dry matter accumulation by the individual kernels multiplied by the number of kernels per plant (Westgate *et al*., 1997). In simple terms, maize grain yield is a product of the number of ears produced and the average weight of the grain on the ears. Thus anything that affects one or both of these factors will significantly affect the final yield (Hatfield *et al*., 1984). According to Hashemi *et al*. (2005), grain yield per unit area is the product of grain yield per plant and number of plants per unit area.

Maize grain yield rises with planting density to some maximum value and then declines. The rate that produces a maximum yield varies with varieties, environment, fertility and planting pattern. For a given hybrid, the yield of maize generally increases as density is raised until one or more factors such as water supply, available plant nutrients and other become limiting. According to Vega *et al*., (2001), maize grain yield is more affected by variations in plant density than other members of the grass family due to its low tillering capacity. Fancelli & Dourado-Neto (2000) found a strong relationship between maize grain yield and plant density. They highlighted that for each production system there is a plant density that optimizes the use of available resources, thereby allowing the expression of maximum attainable grain yield in that environment. According to Tollenaar *et al*. (1997) maize grain yield declines when plant density is increased beyond the optimum plant density, primarily because of decline in the harvest index and increased stem lodging. Such cases represent intense interplant competition for incident photosynthetic photon flux density, soil nutrients and soil water. This results in limited supplies of carbon and nitrogen and consequent increases in barrenness and decreases in kernel number per plant and kernel size (Ottman & Welch, 1989). Maize yield development is a sequential process in which the potential number of ears per plant is determined first, followed by grain number per inflorescence and by grain size. Therefore, variations in the level of carbon and nitrogen induced by different planting rates or any other factor can strongly influence yield and its components sequentially (Jacobs & Pearson, 1991).

Vega *et al*. (2000) found the direct effect of increasing plant density to enhance interplant variability in several phenotypic traits (e.g. biomass, height, anthesis-silking interval, kernel number, etc). Sangoi *et al*., (2002) supported the results of Vega *et al*. (2000), that maize grain yield is associated with the number of kernels per area, which depend on the number of plants per area, number of ears per plant and the number of kernels per ear. Tetio-Khago & Gardner (1988) and Tollenaar *et al*. (1992), found grain yield response to plant density to be mostly associated with number and size of kernels per unit area. Otegui (1995) found a close relationship between grain yield and kernel number for several hybrids grown under different environmental and management conditions.

Hashemi-Dezfouli & Herbert (1992) reported the response of grain yield per unit area to increase in plant density to be parabolic. At low plant density, number of plants limited the yield, while at high plant density number of barren plants limited yield as well. A reduction in grain yield at high plant densities is partly due to an increase in ear barrenness, decrease in number of kernels per ear or both. Daynard & Muldoon (1983) reported that a reduction in the number of kernels per ear might result from fewer flower initials being formed prior to flowering, poor pollination due to asynchrony of tasseling and silking, and abortion of kernels after fertilisation. They suggested that intra-row spacing and competition for water, light and nutrients to be the determinant factors on optimum plant densities for growing environment.

1.1.3. Kernel number per cob (KNC)

Grain yield of maize hybrids differ in their response to plant density and little is known about the yield components underlying these differences (Echarte *et al*., 2000). In general, kernel number accounts for most of the variation in grain yield. Echarte *et al*. (2000) found grain yield response to plant density to be positively and strongly related to number of kernels m^{-2} and negatively and weakly related to weight per kernel. For instance, an increase in plant density from 5 to 14.5 plants m^{-2} increased kernel number per cob by 38 to 56%. However, Tetio-Kagho & Gardner (1988) and Andrade *et al*. (1993) reported that kernel number per plant declines sharply with increasing plant density. This response is the result of a decrease in photosynthetic rate per plant (Edmeades & Daynard, 1979) and hence plant growth rate (Andrade *et al*., 1993). Both directly reflect the reduction in IPAR per plant (Andrade *et al*., 1993). The greatest losses in kernel number per ear occur in plants shaded during the lag phase of grain filling (Kiniry & Ritchie, 1985).

Sangoi *et al*. (2002) reported that the number of potential grain sites per ear measured when silking commenced and before pollination, showed a decline from 550 to 474 grains per ear as population increased. Thus, although high plant density did not affect the time of initiation of the ear primordia, it decreased the number of grain sites per ear available at the time of pollination. Moreover, the decline in grain numbers indicated that under higher plant density a lack of pollination occurred for ears that were delayed in silking together with abortion of some fertile grains thereafter (Hashemi-Dzefouli & Herbert, 1992). Tokatlisdis & Koutroubas (2004) also reported that under higher plant density the reduced assimilate supply causes abortion of kernels, especially at the ear tip. In a more recent study, Maddonni *et al*. (2004) found that maize has a distinctive response to stand density with a sharp decline in kernel number per cob (KNC) and a substantial increase in plant barrenness at plant density beyond the threshold that maximizes grain yield. This response to plant densities derives from the combined effect of: (i) a decrease in photosynthetic rate per plant and in plant growth rate (PGR) (ii) a hierarchical pattern in reproductive development in which tassel growth dominates ear growth (apical dominance). Under stress conditions (e.g., drought, high plant population), ear barrenness occurs because of lack of pollen, incomplete ear pollination and kernel abortion (Carcova & Otegui, 2001).

Maize kernel number per cob (KNC) is associated with plant growth rate (PGRs) during the period bracketing silking (Andrade *et al*., 1999). More kernels set per unit PGRs is probably related to greater dry matter partitioning to the ear and to more kernels set per unit dry matter allocated to the ear during the critical period for kernel set (Echarte *et al*., 2000). Contrarily, kernels per plant, ears per plant and kernel mass decline with increasing plant density, which could be associated with a reduction in plant dry matter accumulation from one week before silking to three weeks after silking (Tollenaar & Stewart, 1992). In addition, the higher kernel mass in an experiment involving ten plants m^{-2} may be attributed to a higher rate of plant dry matter accumulation per kernel during the period from three weeks after silking to physiological maturity. The final kernel number in maize is determined by the amount of photosynthate produced by the crop at flowering (Andrade *et al*., 1993). Gardner & Gardner (1983) and Otegui & Andrade (2000) reported that total plant growth during the period encompassing flowering is not the only factor that influences the number of reproductive sinks set per plant, since the partitioning of dry matter is also influential.

1.1.4. Kernel mass

A final detrimental effect of high plant density on yield components is observed through reduction in the final mass per grain. The rather large differences in mass per grain observed at different plant densities may result from differences in the initial size of the spikelets, in growth rates during the exponential and linear (starch deposition) phases of grain growth or in the duration of those phases (Jones & Simmons, 1986). Lemcoff & Loomis (1986) observed that the initial grain weight after pollination was a key factor in the early growth of the kernel. Thus, at high plant density, the kernel weight was smaller which could in turn be due to delay in development (later initiation of spikelets) or smaller initial size of the spikelet primordial. The final kernel mass correlates strongly with the numbers of cells and starch granules formed, particularly in the endosperm tissue, representing about 85% of the mass of mature maize kernels. Therefore, under high plant density, yield may be restricted by limitations in the capacity for endosperm growth either by number, size or activity of endosperm cells (Salvador & Perarce, 1995). There is also an interaction between kernel position and number in terms of competition for substrates required for growth, which is more accentuated at high plant density. Florets at the tip of the ear are originally smaller and silk later than the basal ones. The growth stage when maximum endosperm cell number occurs is delayed for the tip grains, which also contain fewer endosperm cells and starch granules and exhibit a lower rate of filling than the basal kernels (Jones & Simmons, 1983).

Maddonni *et al*. (1998), found that small kerneled hybrids (kernel weight <300 mg) had a larger kernel number (3500-5500 kernels m^{-2}) than do large kerneled hybrids (kernel weight >300 mg, and 2800-4000 kernels m^{-2}). They indicated that the former depend more on reserve mobilization than the latter for grain filling.

1.1.5. Cob number and barrenness

Sarquis *et al*. (1998) found that plant density strongly influences the rate and duration of crop growth and ultimate fate of multiple ears. They found that a 30% reduction in light interception by the canopy during the crop cycle was enough to completely suppress the development of a second ear. Apparently the reduction of light interception limits source capacity, which in turn could retard second-ear growth severely enough for the latter to be even totally repressed once the ovules in the apical ear have been fertilized (Tetio-Khago & Gardner, 1988). High plant density reduces light interception per plant and it is likely that mutual shading affect source capacity to supply a second ear with photoassimilate. Thus, apical-ear yield seemed to be sink-limited, while source capacity seemed to limit the growth of the second ear. Edmeades *et al*. (2000) demonstrated that assimilates moved preferentially from a leaf to its nearest sink. This implies that leaves above and immediately below the primary ear supply most of the assimilate for grain filling, while assimilates from the lower leaves are more likely to be translocated into the root and lower stem.

At high plant density, the equilibrium between the two ears seemed to be affected due to a stronger competition between them as evidenced by a more severe decrease in grain mass with increasing time between the two pollinations, regardless of which ear was pollinated first (Sarquis *et al*., 1998). The results indicate that in order to complete its growth, a second ear must reach a minimum stage of growth before active grain filling begins in the first ear, as has been postulated by other researchers (Tetio-Khago & Gardner, 1988). The results also supported the idea that total yield per plant would be maximum when both ears were pollinated at the same time (Sarquis *et al*., 1998).

Many researchers have reported that the plant population and the arrangement of the plants have an effect on the number and mass of the ears produced (Hatfield *et al*., 1984). Otegui (1995) found that ears per plant and ear mass are negatively correlated with plant population, while grain yield commonly varies slightly over a wide range of plant population. This suggests compensation between ear number and ear mass. Hashemi-Dezfouli & Herbert (1992) reported that increased plant density during drier periods decreases the mass and diameter of cobs, diameter and number of kernels per cob, but not the number of kernels per row as well as weight of kernels.

The failure of plants to produce ears (Barrenness) has been reported as one of the major factors limiting optimum conversion of light energy to grain in maize grown at high plant densities (Buren *et al*., 1974). Grain yield of many hybrids planted at high densities are markedly reduced by barrenness. Therefore, it is important that factors influencing barrenness be determined and understood to permit selection of genotypes that are tolerant of high plant densities (Buren *et al*., 1974). Ritchie & Alagarswamy (2003) found high maize yields at plant densities ranging from seven to ten plants m^{-2}, but barrenness occurred more frequently when plant densities exceed 10 plants m^{-2}. Thus, plant densities influence both plant growth rate (PGR) and barrenness. In relating barrenness to plant growth rate, Andrade *et al*. (1999) found that maize plants were barren when plant growth rate averaged about 1.0 g per day during the 30-d period bracketing silking. Maize genotypes appear to have major genetic differences in barrenness. Tollenaar & Aguilera (1992) found that lower barrenness in modern maize hybrids compared with older hybrids at higher plant densities was associated with higher plant growth rate from one week presilking to three weeks postsilking. Additionally, Andrade *et al*. (1999) related average intercepted photosynthetically active radiation (AIPAR) to barrenness and found a threshold AIPAR of 0.34 MJ plant d^{-1} during ear development stage was necessary to avoid barrenness.

1.1.6. Leaf area, leaf area index and crop growth

Watson (1997) defined leaf area index of a crop as the one-sided area of green leaf tissue per unit area of land occupied by that crop. That is the area of leaf per area of land. It is a key plant growth parameter that is frequently measured and estimated from leaf shape characteristics (Stewart & Dwyer, 1999). Leaf area index (LAI) and distribution of leaf area within a maize canopy are major factors determining total light interception, which affects photosynthesis, transpiration, and dry matter accumulation. It can be estimated and used in crop growth models to calculate photosynthesis, assimilate partitioning, gas and energy exchange (Fortin *et al*., 1994). During the early vegetative stage of growth, leaf area determines total light interception. Thus, conditions favouring maximum area per leaf should optimise CO_2 fixation during that period (Morrison *et al*., 1992). It is important to note that only 50 per cent of incident solar radiation can be used as photosynthetically active radiation (PAR). The remaining energy is of no value in photosynthesis and if absorbed, serves only to increase the temperature of the leaf (Monteith, 1981).

The efficient interception of radiant energy incident to the crop surface requires adequate leaf area, uniformly distributed to give complete ground cover and that could be achieved by manipulating stand density and distribution over the land surface (Modarres *et al*, 1998). The capacity of the crop to intercept photosynthetically active radiation and synthesize carbohydrates for growth is a nonlinear function of LAI (Andrade *et al*., 2002). Kiniry & Knievel (1995) reported that in the absence of nutrient deficiencies, temperature extremes, or water stress, solar radiation intercepted by plant is the major limitation to growth, development and yield.

Stickler (1984) showed that the combined leaf area per plant for the primary ear leaf with the first above and below the ear decreased from 2300 cm^{-2} at 39500 plants ha^{-1} to 2150 cm^{-2} at 59500 plants ha^{-1}. However, the leaf area produced on the main stalk does not decrease in inverse proportion to an increase in plant density; thus area changes must be attributed to differences in silking with density. Major & Dynard (1972) reported that LAI of 2.6 is optimum for grain yield in hybrids while 2.0 is considered optimum for inbreds. At optimum LAI, about 90% of the incoming solar radiation is intercepted by the crop canopy (Major *et al*., 1972). Maize grain yield tend to be linearly related to LAI at silking period. The LAI values greater than 4.0 substantially reduce the depth of light penetration into normal leaf canopies and greatly reduce yield. Dry matter produced in maize with a LAI of 3.3 by the top, middle and bottom leaves is of the ratio of 4:21:1. Thus, the low rate in the bottom leaves is probably due to shading by the above leaf canopy at a high LAI and leaf age. The high rate in the middle is probably due to close proximity of the developing grain, which provides for a large sink for photosynthates (Stickler, 1984).

The efficiency of conversion of intercepted solar radiation into economic maize yields could decrease with high plant density because of mutual shading of plants (Buren, 1974). Boyat *et al*., (1990) reported that increasing plant density accelerated leaf senescence, increased the shading of leaves, and reduced the net assimilation of individual plants. Their results also showed that an increase in plant population of 2-13 plants per m^{-2} decreased the net assimilation per plant from 0.85 to 0.11 mg CO_2 m^{-2} s^{-1}, but increased grain yield per area. This increase in grain yield could therefore be attributed to increase in leaf area index (LAI) and net crop assimilation (Dwyer *et al*., 1992).

1.1.7. Flowering/tasseling

In maize (*Zea mays L.*), tassel initiation is the first visible sign that a plant has shifted from the vegetative to the reproductive stage of development (Russel & Stuber, 1983). Contrarily, some authors reported that, it is incorrect to say that reproductive development begins with the initiation of the tassel because the early initials of ears are visible as buds at the axils of the lower leaves before the tassel is differentiated. Approximately 30 days after planting, when the stem is only 2 cm long and the plant just knee-high, the tassel is initiated. At this stage, the growing point is switched only partly from producing leaves to producing the terminal reproductive structure, the tassel.

Tokatlidis & Koutroubas (2004) reported that high plant density affects the required interval for pollen shedding and silk emergence. The time from planting to silking increased from 84 to 95 days as density increased from five to 20 plants m^{-2}. Additionally, Tokatlidis & Koutroubas (2004) reported that since the time gap between pollen shedding and silking increased with increase in plant density from almost zero to nine days. This in combination with the fact that plants not shedding pollen and not silking were observed only at the higher plant density of 15 and 20 plants m^{-2}, contributed to increase in ear barrenness. Similar results were obtained under three plant densities by Hashemi-Dzefouli & Herbert (1992). Tassel emergence was slightly affected by plant density changes. Pollen shedding and 100% silking were observed at the same time under the lower plant density of three plants m^{-2}. Conversely, the time for 100% silking was delayed by up to five days as density increased to seven plants m^{-2}, and under the higher plant density of 12 plants m^{-2} about 10% of the plants did not show any silk seven days after anthesis. The number of barren plants increased linearly as the plant density increased. The same holds true for results of Sangoi *et al*. (2002) who showed a linear elongation of the pollen-to-silking interval with increasing density from three to 10 plants m^{-2} of the three maize hybrids studied. The pollen-to-silking interval increased from five to 13 days for the two older hybrids and five to 11 days for the newer hybrids. Sangoi *et al*. (2002) concluded that high plant density lengthen the gap between pollen shedding and silking, while on the other hand barrenness could be stimulated even in the case of density -tolerant hybrids, since any environmental adversity (i.e. high temperatures) may prevent pollination because of its detrimental effect on the limited pollen during silk emergence. Undoubtedly, the increased gap between pollen shedding and silking under higher plant density constitutes a key factor for increased ear barrenness and therefore influences negatively the final grain yield (Tokatlisdis & Koutroubas, 2004). Hashemi-Dzefouli & Herbert (1992) also reported that high plant densities delay silk emergence that lead to decrease in kernel number per ear, increased number of barren plants and reduction in total grain yield.

Tetio-Kagho & Gardner (1988) reported the effect of high plant densities on extension of the tasseling-to-silking interval and lack of kernel filling to be more detrimental. High plant densities enhance interplant competition for assimilates, particularly during the period bracketing silking, favouring apical dominance and decreasing the ratio of ear to tassel growth rate (Edmeades *et al*., 2000). Similar results were reported by Otegui *et al*. (1995) that at silking, the amount of dry mass partitioned to the ear to be exponentially associated with the summed intercepted photosynthetic active radiation (IPAR) prior to silking. This relationship supported the idea that during this period the ear is a dominated organ (Tollenaar, 1997), competing for photoassimilates with leaves, tassel and stem (dominating organs). As the demand from dominating organs is satisfied, then more resources are allocated to the ear with resultant ant higher proportionally increase in ear dry mass than shoot dry mass.

1.1.8. Plant height

Plant height is a genetic trait. Thus, the number and length of the internodes determine the height of the stalk. In this way, plant height can vary from 0.3 m to 7.0 m, depending on the variety and growing conditions (Gynes-Hegyi *et al*., 2002). Usually, early maturing varieties are shorter and late maturing ones are taller. In a tropical climate where the growing season may be as long as 11 months, some late maturing varieties can reach a height of 7 m (Koester *et al*., 1993).

Yokozawa & Hara (1995) cited that the height of the final plant and the diameter of its stalk are strongly influenced by environmental conditions during stem elongation. Temperature and photoperiod may influence stalk height by affecting the number of internodes. However, there are more direct effects resulting from moisture stress, nutrition, temperature, pests and diseases and light quantity and quality (Baggett & Kean, 1989). Moisture stress could simply affect the length of internodes probably by inhibiting the elongation of developing cells.

It has often been observed in experiments involving different plant densities that maize plants are taller as mutual shading increases, although there is considerable varietal variation in this characteristic (Yokozawa & Hara, 1995). Thus, plants that grow within a dense canopy under high plant density receive a different quality of light, enriched with far red (FR) and impoverished in red (R) radiation. This high FR/R ratio triggers many morphological changes in plant architecture, stimulating stem elongation, favouring apical dominance and decrease in stem diameter (Rajcan & Swanton, 2001). In addition, Troyer & Rosenbrook (1991) reported that stalk breakage and ear droppage increase because crowded maize plants have smaller diameter stems and shanks due to mutual shading. Such changes make maize stalks more susceptible to breakage before kernels reach physiological maturity. Stalk lodging represents one of the most serious constraints to the use of high plant densities in maize (Argenta *et al*., 2001). Thus, many high-yielding hybrids are often rejected during development because of stalk lodging.

1.2. Planting date effects

1.2.1. General background

In South Africa, the occurrence of mid-summer drought from approximately mid-December to mid-January, which can be expected over the greater part of the production area, plays an important role in determining planting date (ARC-GCI, 1999). Therefore, planting date should be scheduled such that the growth stages of maize most sensitive to heat and water stress do not coincide with mid-summer droughts. Based on varying weather conditions in South Africa, the broad optimum planting dates are as follows: for cooler eastern producing areas, from the beginning of October to the first week of November; for central regions from the last week in October to mid-November; for drier western areas from the last two weeks in November to mid-December (ARC-GCI, 2002; Du Toit *et al*., 2002)

Of all the management aspects of growing a maize crop (cultivar selection, plant density, amount and timing of fertilizers, etc.), planting date is probably the most subject to variation because of the very great differences in weather at planting time between seasons and within the range of climates (Otegui *et al*., 1995). The year-to-year variation in plant establishment, pest and disease incidence makes it difficult to predict optimum planting dates for maize crops (Oktem, 2000). In practice, recommended dates are normally drawn up from the results of long-running series of agronomic experiments, which can give mean planting dates for highest yield together with realistic estimates of expected yield penalties for each week of delay in planting (Lauer *et al*., 1999). However, in accepting such guidelines, several reservations must be appreciated in addition to the fact that use of the recommended date is not a guarantee of highest yield for that season (Oktem, 2000). First, there can be very large differences in the pattern of response to planting date among cultivars. Secondly, the interactions between plant diseases and planting date are not fully understood.

1.2.2. Grain yield

Maize planted earlier develops better and has a higher yield potential because the vegetative period of its development occurs in the cooler part of the season when moisture stress is less likely (Aldrich *et al*., 1986). Corke & Kannenberg (1989) reported that the optimum uses of limited growing period for maize is essential to maximize grain yield in short season areas. Generally, there are many benefits related to early planting date compared to late planting date and this include a long growth duration that allows a greater choice of hybrid maturities and wider window of opportunities for replant decisions. Again, earlier planting tends to place the tasseling and silking period ahead of the greatest risk of moisture stress and drought damage (Otegui & Melon, 1997). In addition, Sheperd *et al*., (1991) reported that early planting date could contribute significantly to higher maize yields. The authors also highlighted that, higher yield is not the only advantage of early planting because other benefits can also be achieved from high plant density and high fertilizer rates. It also allows harvesting earlier in the season when conditions are usually better and field and time losses can be minimized (Hicks *et al*., 1993). In addition, very simply early planting increases net returns without adding production costs.

On the other hand late planting or planting after the optimum period consistently resulted in lower yields. Delayed planting shortens the effective growing season for maize, increasing the risk of exposure to lethal cold temperatures late in the season before grain maturation. According to Aldrich *et al*., (1975) yield reduction in late plantings could be attributed to a short growth duration, insect and disease pressure, heat and moisture stress during pollination. These results were in agreement with those by Otegui & Melon (1997), who reported that delayed plantings are generally accompanied by increased temperatures during the growing season, which accelerate crop development and decrease accumulated solar radiation, resulting in less biomass production, kernel set and grain yield.

In principle, delay in planting beyond a given date results in a progressive reduction in the potential yield of the crop, because an increasing proportion of the available solar radiation will not be intercepted by the crop canopy. In practice, yield does normally decline with delay in planting due to yield penalties encountered. However, the results of planting date experiments can be highly inconsistent between seasons and sites. For example, it is not unusual for a relatively late sown crop to out yield the control crop sown within what would be considered to be the optimum period (Green *et al*., 1985). There are several reasons for such inconsistencies and unexpected results. First, the soil conditions at different planting dates will inevitably be different and unfavourable conditions (excess or deficiency of soil moisture, serious incidence of disease, etc.) can occur at almost any point during the normal planting dates. Consequently, the observed differences in the performance of crops sown on different dates are commonly a reflection of differences in established plant density. Secondly, crops sown at different dates pass through each developmental stage at slightly different times and, therefore, under different environmental conditions (especially photoperiod and temperature); thus any one of the developmental stages which determine the components of yield could conceivably occur under more or less favourable conditions in late-sown crops. For these reasons, it is not easy to carry out a critical comparison of the grain yields and their components of the different crops in a sowing date experiment. Scarsbrook & Doss (1972) reported that yield of maize is function of many plant and environmental factors which are often interrelated.

1.2.3. Kernel number per cob (KNC)

Although the acceleration in the rate of crop development associated with increased plant density or with delay in planting date means that the duration of the phase of spikelet initiation is reduced, the overall effects of these two management factors upon ear size are different (Bassetti & Westgate, 1993). In the case of plant density, the rate of spikelet initiation is relatively unaffected, with the result that ear size declines progressively with increasing seeding rate. In contrast, variation in planting date is commonly found to have an influence upon the number of grains per ear (Harris, 1984). Otegui & Melon (1997) reported that planting dates affect the kernel set and flower synchrony within the ear of maize. Similarly, Derieux *et al*. (1985) observed a significant relationship between kernel set per row and final ovule number per row for certain genotypes planted on different dates. Cirilo & Andrade (1994) found no effect of planting date on spikelet primordial counted at silking in the apical ears of two maize hybrids. They suggested that kernel abortion rather than a morphogenetic process was the dominant factor determining the final kernel set.

Reduced kernels per ear are the most consistent, irreversible component of yield reduction under drought stress (Anderson *et al*., 2004). The number of florets that may become kernels cannot exceed exposed silk number and declines from this potential as silks lose receptivity and senesce with age (Bassetti & Westgate, 1993). Hybrids with faster silk growth rates may have more silks available for pollination at the beginning of flowering. However, when environmental conditions are below optimum, kernel number may be limited by asynchrony (pollen is not shed when silks are exposed or receptive) (Anderson *et al*., 2004), loss of silk receptivity (silk is no longer functional to support pollen tube growth (Bassetti & Westgate, 1993) or developmental failure of the ovary. Such limitations to kernel number may have drastic impacts on grain or seed production profitability and may be influenced by silk characteristics for a given hybrid or inbred (Anderson *et al*., 2004).

1.2.4. Kernel mass

Because of other aspects of the acceleration of development (in particular, lower crop dry mass at anthesis), there may also be a tendency for later-planted crops to give lighter grains. Thus in most findings, grain mass is either unaffected or reduced by later planting by up to about 10 percent (Taylor & Blackett, 1982). These generally support the idea that the individual grain mass for a given cultivar is a relative stable character (Maddonni *et al*., 2004). However, when delay in the start of grain filling by a few days coincides with a rapid deterioration in the environment, much larger effects can be anticipated. In summary, grain yield generally declines with delay in sowing, principally as a consequence of decreases in ear number, but also in some cases because of small decreases in individual grain mass. Maddonni *et al*. (2004) reported that kernel mass is conditioned by post-silking crop growth, with more dependence on reserve mobilization in hybrids with small kernels and large kernel number than in hybrids with fewer kernels of large size. Thus, decreased incident solar radiation reduced final kernel mass through reductions in biomass production per kernel, but low temperatures impair grain filling through reductions in biomass partitioning to kernels.

1.2.5. Growth and dry matter yield

Variation in maize planting date modifies the radiative and thermal conditions during growth. The amount of incident radiation and the proportion of this radiation that is intercepted by the crop directly determine crop growth rate (Cirilo & Andrade, 1994). Cirilo & Andrade (1994) reported that delays in planting date determined important reductions in the amount of incident radiation accumulated from emergence to silking, because it hastened development. Inversely, high temperatures during early growth of late plantings hastened leaf area development as shown by their high early percentage photosynthetic active radiation (PAR) interception values. Several authors reported similar temperature effects on leaf appearance rate and on leaf expansion in maize (Thiagarajah & Hunt, 1982; Hesketh & Warrington, 1989).

Cirilo & Andrade (1994) reported that at the grain filling stage, plants exposed to low radiation and low temperature in late plantings, compared to early plantings, will result in decreased dry matter production. Late plantings also showed a higher non-structural carbohydrate concentration in stems at mid-grain filling than the early plantings. This suggested that low temperatures during grain filling in late plantings limited kernel growth as well as crop photosynthesis. Thus, the ratio between final kernel number and dry matter at silking dropped dramatically for the late plantings, indicating a predominance of vegetative growth over reproductive growth.

In general, late plantings will result in high crop growth rates during the vegetative period because of high radiation use efficiency (RUE) and high percentage radiation interception, but conversely result in low crop rates during grain filling because of low RUE and low incident radiation. The inverse holds true for early plantings (Cirilo & Andrade, 1994). In addition, Maddonni *et al.* (2004) found that in late plantings, both solar radiation and temperature decline during grain filling. Thus, lowered solar radiation resulted in grain growth in excess of biomass production, indicating a possible source limitation. On the other hand, low temperature may have a negative effect on kernel weight through reductions in both radiation use efficiency and biomass partitioning to the grains (Andrade *et al*., 1993).

1.2.6. Silking/tasseling and physiological maturity

Tollenaar & Bruulsema (1988) found that the time from silking to physiological maturity lengthened with delay in planting dates. This was because cool temperatures late in the season of the latest planted crops prevented true maturity since grains never formed a true black layer. Daynard (1972) found that delayed planting increased the thermal time interval from planting to mid-silking but decreased the thermal interval between mid-silking and black layer formation. Sutton & Stucker (1974) reported that thermal intervals between plantings and black layer decreased as planting was delayed from early to late planting. Thus late plantings reduced cumulative intercepted PAR from silking to physiological maturity mainly because of their low values of daily incident radiation (Tollenaar & Aguilera, 1992). On the other hand, radiation use efficiency (RUE) for late planting was high in the early growing stages and low during the cool grain filling period. The opposite was true for early plantings that showed low RUE from emergence to silking and sustained during most of the grain filling period when temperatures were more favourable for the photosynthetic process (Cirilo & Andrade, 1994). In addition, the period between emergence and anthesis of maize hybrids planted earlier in the season can be up to two weeks longer than when the same cultivar is planted later (Sangoi, 1993). During this extra period, plants will uptake more solar radiation and store the energy because the lower temperatures limit their growth and consumption of this energy. As a result of this slower pattern of development, early-planted maize plants are smaller and less leafy at anthesis (Sangoi *et al*., 1998; Silva *et al*., 1998).

Stewart *et al*. (1997) reported that delayed planting increased growing degree days (GDDs) to black layer for three hybrids in a drought year but decreased GDDs to black layer for the same three hybrids in the following year under less stressful conditions. According to the Canadian studies, the GDDs system provides a reliable estimate of thermal time required for vegetative (interval between planting and silking) development (Stewart *et al*., 1997). Estimates of thermal time required for grain filling (period between silking and maturity) vary considerably, however, with the GDD system frequently overestimating thermal time required for grain filling. A better understanding of the phenological response of maize to thermal time as planting is delayed is necessary to improve the accuracy of hybrid maturity selection for late planting situations (Barger, 1969).

1.3. Short and ultra-short growing season maize cultivars

1.3.1. General background

Production of maize in short growing season areas poses two major problems. Firstly, maize grown in those areas has a smaller leaf area than maize grown in long growing season areas (Dijak *et al*., 1999). This is largely due to smaller plant stature accompanied by reduced leaf number and size, which leads to inefficient capture of sunlight (Chase & Nanda, 1967; Hunter *et al*., 1974). In addition, one concern for production of short season maize hybrids is that there would be less time for leaf area production and for interception of photosynthetically active radiation (PAR). Any reduction in leaf area or season light interception would likely result in decreased yield potential (Tollenaar & Bruulsema, 1998). Hunter (1980) was able to increase the grain yield of short growing season maize by increasing leaf area per plant. Secondly, in very short growing season areas the seasonal thermal time available may be insufficient for grain maize to mature. Extension of maize production into new short season areas requires the availability of genetic material that accumulates leaf area and matures more rapidly than genotypes that have been used in the past (Modarrres *et al*., 1997). Thus the development of maize varieties that produce leaf area and mature quickly would increase production in mid to short-season areas. The leafy and reduced stature traits both can make contribution to this end, although they have not previously been combined (Modarres *et al*., 1998). Table 1.1 and 1.2 present previous results of short and ultra-short growth period maize cultivars during 2003 and 2006 growing periods at different locations in South Africa.

Table 1.1 Mean yield of short and ultra-short growth cultivars in ton/ha in 2003 (Maize Information Guide, 2003)

Cultivars	Potchefstroom (dryland)	Vaalharts (irrigation)	Bethlehem (dryland)	Upington (irrigation)
ENERGY	4.85	8.74	5.26	13.90
DKC63-20	5.92	10.90	6.57	11.70
PAN6017	3.09	11.70	5.93	9.22
Phb3203	3.88	9.85	5.90	11.50
SNK6025	4.53	4.53	5.64	10.40
LS8525	2.96	9.58	5.60	10.30
MAVERIK	4.06	8.04	4.58	11.60
CAP122-50	3.28	6.99	3.82	7.29
WOODRIVER	3.55	9.26	5.11	11.60
SC401	2.46	10.30	4.31	10.20

Table 1.2 Mean grain yield of short and ultra-short growing season maize cultivars in 38 trials (ARC-GCI, Maize Information Guide, 2006)

Cultivar	5ton	6ton	7ton	8ton	9ton	10ton	Mean
PAN6017	4.21	5.27	6.33	7.39	8.44	9.50	5.84
DKC63-20	4.28	5.23	6.19	7.15	8.10	9.06	5.87
Phb3203	4.14	5.06	5.97	6.89	7.81	8.72	5.54
ENERGY	3.64	4.60	5.55	6.51	7.47	8.42	5.38

1.3.2. Growth, yield and yield components

In general, long growing season maize hybrids are higher yielding, particularly under conditions of good moisture and nutrients (Cross, 1990). However, as moisture conditions become more limiting, the earlier maturing hybrids will have greater yield advantage. Hybrids with short to medium-quick maturity are likely to flower before mid-summer drought. Therefore, it is important to plant early maturing hybrids because of excessive heat that normally occurs at critical growth stages. Maize is extremely susceptible to drought stress at flowering. Stress occurring on a single day at this stage results in twice as much grain yield reduction as any other stage (Grant *et* *al*, 1989; NeSmith & Ritchie, 1992). The extreme susceptibility of maize to drought stress has been attributed to the spatial separation of male and female flowers on the same plant, differential partitioning of assimilates in favour of the tassel versus the ear when the plants are stressed at flowering (Edmeades *et al*., 1993), and the negative effects of water deficits on hormonal and enzymatic activities in the newly fertilized ovary (Westgate *et al*., 1997). Drought at flowering was also reported to reduce flux of assimilates, especially sucrose to developing kernels, resulting in abortion of fertilized kernels shortly after fertilization (Schussler & Westgate, 1995; Westgate, 1997). In addition, by flowering time farmers can no longer adjust management practices such as fertilizer application, weed control and replanting (Hall *et al*., 1981). It can be argued that, growing early maturing maize cultivars or ultra short maize cultivars that mature approximately in less than 100-150 days and that can be harvested 20-30 days before their normal counterparts could minimize stress and maximize production (Lewis, 1998). That is short growing season hybrids can cope better with low rainfall than full season hybrids. These can narrow the hunger gap and reduce the risk from drought when rainfall distribution becomes erratic or poor.

Lewis (1998) reported that shorter season hybrids could yield more than long season hybrids because they reach the critical flowering stage before mid-summer droughts. The short season hybrids seem to maximize the growing season, and they potentially pollinate before the hottest part of the summer. In addition, Alessi & Power, (1975) mentioned that early maturing cultivars offer flexibility in planting dates under rainfed conditions, opportunity for increasing cropping intensity and flexibility for escaping drought that may occur at the beginning or end of the growing season. Furthermore, early maturing cultivars facilitate early land clearing and help conserve moisture for the next sown crop (Sheperd *et al*., 1991). Early maturing cultivars also permit an early harvest of the crop when the scarcity of food occurs among most of the subsistence farmers (Hicks *et al*., 1993). A good yield advantage of short season hybrids over long season hybrids were obtained over a period of two years (Lewis, 1998).

Corke & Kannenberg (1989) discussed and showed that short season maize production areas tend to be source limited (i.e. lacking in assimilate supply to the grain production), which normally resulted in reduced yield. Hunter (1980) supported the findings and mentioned that it should not be surprising that source is a limiting factor in short season maize since short season hybrids have small plant stature and more importantly have the tendency to produce reduced leaf number and size. Evidence for this comes from two research approaches: one approach involved the manipulation of sink and source by the use of light reflectors and shading during the kernel establishment period (silking plus two weeks) and during the grain filling period (from two weeks after silking to maturity). In that study yield was affected more by alterations in assimilate supply during the grain filling period, indicating a predominant source limitation for grain yield in a short growing season environment (Hunter, 1980). The second approach examined the contribution of stalk carbohydrate reserves to the grain yield. Several researchers have demonstrated extensive translocation of stalk carbohydrate reserves to the grain during the grain filling period. Stalk carbohydrate reserves are relocated to the grain when the existing leaf canopy cannot meet the carbohydrate demands of the developing ear. Thus the degree of translocation can be accelerated by premature leaf loss or reduced by limited kernel set.

Optimal use of the limited heat units available for maize production in short season areas requires a balance between vegetative phase duration and grain filling duration. The vegetative phase duration is positively correlated with leaf area and leaf number (Muldoon *et al*., 1984). A positive correlation has also been shown to exist between grain yield and filling period duration in both long growing season and short growing season materials (Daynard & Kannenberg, 1976). Maize hybrids suited for short season production areas tend to be source limited (Tollenaar, 1977; Hunter, 1980). Increasing the length of either one of the vegetative or grain filling periods would require a concomitant decrease in the duration of the other period. It has been suggested that productivity of short season hybrids could be increased by an increased rate of grain filling and increased rate of leaf area production (Hunter, 1980; Cross, 1991). Selecting hybrids with larger leaf area index and by increasing plant density could also increase yield (Daynard & Kannenberg, 1976). On the other hand there is a positive relationship between days to silking and leaf area (Cross & Zuber, 1973), so that selection for delayed silking should increase leaf area per plant. However, in short season areas the limited growing season restricts the use of this strategy. To overcome this problem, Hunter (1980) suggested that breeders should produce genotypes with rapid leaf area expansion during the pre-silking stage without increasing vegetative phase duration.

1.3.3. Effect of plant density on grain yield and yield components

In general, short growth season hybrids require higher plant densities for maximum grain yield than the long season hybrids (Silvar, 1992; Tollenaar, 1992). This occurs because short season hybrids are normally smaller, produce less leaves, have lower leaf area per plant and present fewer self-shading problems than the long season hybrids. Therefore, for short season hybrids it is necessary to have a greater number of plants per area to generate the leaf area index that provides maximum interception of solar radiation, an essential step to maximize grain yield.

The occurrence of mid to late summer drought limits the productivity of dryland or nonirrigated maize (*Zea mays L.*) production (Edwards *et al*., 2005). It can be speculated that by increasing plant density and narrowing row spacing, short season maize hybrids would have similar yield or yield better than long season hybrids currently grown. Mid-season drought is a recurrent problem in many maize producing areas around the world and a great deal of efforts need to be directed towards developing plants that can physiologically withstand drought stress or management systems that can avoid drought stress altogether (Edmeades *et al*., 1997; Howell *et al*., 1998; Larson & Clegg, 1999; Norwood, 2001). However, avoidance of drought stress can be achieved by matching crop phenology with prevailing rainfall patterns and is a relatively simple concept. Furthermore, agricultural producers can immediately reap benefits without the need for introgression of physiological traits for drought tolerance. Alternatively, supplemental irrigation can be used to avoid drought stress and ensure adequate grain yield. Previous research in moisture-limited environments has indicated that maize crop maturity can be an effective tool to reduce irrigation requirements and avoid drought (Howell *et al*., 1998; Larson & Clegg, 1999).

Therefore, short season maize hybrids would seemingly have potential for avoiding drought in many maize-producing areas. Some researchers also speculated that inadequate assimilate supply that can occur in short season regions may limit final grain yield (Modarres *et al*., 1998). Therefore, narrow row spacing and plant densities higher than current recommendations are required for short season maize hybrids to ensure rapid canopy closure and full light interception (Andrade *et al*., 2002; Pedersen & Lauer, 2002; Westgate *et al*., 1997). The response to narrow row spacing and high plant density, however, has been shown to be hybrid specific in some environments (Westgate *et al*., 1997). The differential response to increased plant density among environments creates a need for additional research to elucidate a mechanistic, rather than empirical approach to determining optimal plant density of maize.

Larson & Clegg (1999) found that a full-season hybrid produced a maximum yield at 85000 plants ha^{-1} if no stress occurred, but that densities should be reduced to between 45000 and 65000 plants ha^{-1} under unfavourable environments. However, they suggested that the use of early maturing hybrids might improve yield stability because they can pollinate before the late summer droughts begin (Norwood, 2001). Duncan (1958; 1972) found that late maturing maize hybrids out-yielded early maturing maize hybrids provided they matured before a killing frost. The author also reported that early maturing hybrids planted at higher plant densities produced higher grain yields than late hybrids when supplied with adequate nutrients. Carson *et al*., (1966) evaluated the grain yield response of three maize hybrids with maturity group (early, medium and late) at three plant densities (48000, 72000 and 96000 plants ha^{-1}) at two planting dates (early and late). The latest maturing hybrid in that experiment was the highest yielding at the early date, low planting rate combination, but the earliest hybrids at the five other rate-date comparisons out-yielded the late hybrids by an average of 15%. Several authors worldwide have confirmed the importance of plant density. As early as 1930, Olson (1930) reported significant grain yield responses at different plant densities in early maturing varieties. Howes Alberta, a very early maturing variety gave a significant grain yield increase when planting rates were increased from 20000 to 50000 plants ha^{-1}. Wiidakas (1958) found that early maturing maize varieties planted at 40000 plants ha^{-1} produced higher grain yields than late maturing varieties. Troyer (1968) observed that the smaller, earlier maturing maize varieties tended to withstand crowding better than the larger, later maturing varieties. Thus, high plant density and uniform plant distribution within the row tended to compensate for the smaller plant size and lower yield per plant of the early maturing varieties. Investigating the effect of plant population on two maize varieties, Dowker (1963) reported that at above seasonal rainfall of 550 mm, 36000 plants ha^{-1}

gave the best yield for a late variety that matured in five and half months. For an early variety maturing in four months, 72000 plants ha^{-1} gave the highest yields. However, below this amount of seasonal rainfall, 12000 to 18000 plants ha^{-1} gave superior yields for the late variety, whereas the early variety had its maximum yield at a plant density of 36000 plants ha^{-1}. Rodriquez (1987) recommended a plant density of 50000 to 65000 plants ha^{-1} for intermediate maturity maize varieties and a population density of 65000 to 90000 plants ha^{-1} for early varieties in the semi-arid areas under optimum fertility and rainfall conditions. He recommended a plant density of about 25000 plants ha^{-1} under very dry and poor soil fertility for intermediate varieties.

Alessi & Power (1975) reported that in the Corn Belt of the USA, climate tends to favour moderately late maturing hybrids for maximum corn growth, but in the semi-arid regions these hybrids are of limited value due to unfavourable climatic conditions. However, in South African conditions, these cultivars could result in low yield because of erratic and low rainfall distribution late in the growing season (ARC-GCI, 2002). A full-season hybrid generally produces more grain yield than a short-season hybrid when planted early and growing season length is not a yield-limiting factor (ARC-GCI, 2002). However, Staggenborg *et al*. (1999) reported that yields of short-season hybrids were equal to or greater than yields of full-season hybrids at later planting dates.

In a plant density study by Alessi & Power (1974), short season hybrids produced fewer barren stalks and higher ear mass than the long season hybrids at all densities However, for both hybrids the number of ears per stalk and ear mass decreased as density increased (Alessi & Power, 1974). The ear mass was similar for both hybrids during favourable years, but short season hybrids produced heavier ear mass during less favourable years than long season hybrids (Alessi & Power, 1975). In general, the short season hybrid produced 19% more grain yield than the long season hybrid (Alessi & Power, 1974). Apart from grain yield, dry matter production by the long season hybrids averaged 12% greater than that of the shorter season hybrids.

1.3.4. Effect of plant density on leaf area, leaf area index and dry matter yield

Modarres *et al.* (1998) reported that short season maize hybrids have less leaf area than long season maize hybrids, largely because of small plant stature accompanied by decreased leaf number and size. Thus plants grown under a long season environment have more leaves, large mean leaf size, greater leaf area and greater ear yield (Modarres *et al*., 1998). The longer a crop stayed in the field, the greater the yield potential is due to the number of days available to capture sunlight and transform it into carbohydrates and yields (Dennis, 1996). They concluded that a greater assimilate supply produced by the larger leaf area increased yields. Cross (1990) found that part of the yield increase was mainly due to a five days increase in the grain filling period for plants grown under long photo periods. Hanway (1989) reported that the short season hybrids produced much less leaf material than did the long season hybrids as indicated by the leaf blade weights removed by 100% defoliation at leaf stage six. Moreover, the leaf weights of long season hybrids at the lowest plant density of 29060 plants ha^{-1} were very nearly equivalent to that of the short season hybrids at the highest density, with twice as many plants per unit area (Hanway, 1989). Cross (1990) also reported that short season hybrids have smaller leaf area indices than long season hybrids, mainly due to their reduced leaf number and size. He added that the differences in leaf weights between the hybrids could be directly related to the length of the vegetative periods of the hybrids.

Hunter (1977) reported that the maximum LAIs of short season hybrids at normal plant density were low, in the range of 2.0 to 2.7. The author argued that at these LAIs, a maize canopy could intercept as much as 75% of full sunlight. Additionally, Hunter (1980) was able to increase the grain yield of short season maize by increasing the leaf area per unit area through increase in plant density. Thus, plants established with a long photoperiod had more leaves, larger mean leaf size, greater leaf area, and greater ear yields than plants established in short photoperiod conditions. He then concluded that increasing leaf area is probable approaches to increasing assimilate supply with resultant increase in yield. Thus one of the simplest ways of increasing leaf area index is to increase plant density (Hunter, 1977). In short growing season areas this approach has considerable merit and is currently being utilized worldwide. Contrarily, in some parts of short season areas, the use of significantly higher plant densities is being prohibited by the lack of sufficient stalk quality to overcome the increased plant lodging commonly associated with higher plant densities (Cross, 1977). Olson & Sander (1988) reported that leaf area index can be improved by increasing plant density, but this approach could also lead to increases seed costs to growers and increase susceptibility to stalk lodging. Alessi & Power (1975) studied short season maize hybrids and found that increasing plant densities up to 74000 plants ha^{-1} produced LAIs of 1.8 to 4.9, depending on the hybrid and season. Although total dry matter production was usually high at high plant densities, the optimum densities for grain yields were in the range of 30000 to 40000 plants ha^{-1}. At higher plant densities, a higher proportion of dry matter was partitioned into stalks at the expense of ears. An alternative approach is to develop hybrids with a high rate of leaf area production. Hunter (1977) reported that selecting genotypes with a high rate of leaf area production during the presilking stage could be the second approach to increasing leaf area index. Shaver (1983) pointed out that leaf area index can be improved in two ways: breeding for increased leaf area per plant and increasing plant density. The author reported that one breeding strategy available for increasing leaf area per plant is to incorporate the leafy trait into the inbred lines. Modarres *et al*. (1998) demonstrated that plants bearing the leafy trait are characterized by extra leaves above the ear, low ear placement, highly lignified stalks and leaf parts, early maturities and high yield potential.

LAI is important in determining radiation interception up to a value of about 4.0 in maize; after that additional leaf area has little effect on light interception (Tollenaar *et al*., 1997). Plant density is a key determinant of LAI and radiation interception. Most of the maize hybrids currently cultivated in Southern Brazil are short season growers that have small plant height, lower leaf number and more upright leaves in comparison to the long season hybrids used in the past (Almeida *et al*., 2000). Sangoi & Salvador (1998) reported that in those cultivars with small and less leaves, the level of interference or competition of each individual over the others is lower. Smaller plants with shorter stems, fewer and more erect leaves will reduce relative production and maintenance costs (e.g. water, nutrients and assimilates) per plant (Loomis & Connor, 1992). In addition, a lower amount of vegetative biomass per plant allows the use of high plant density, which in turn increases leaf area index (LAI). Increments in LAI provide more effective light interception (Tollenaar *et al*., 1997). With greater amounts of solar radiation intercepted, increases in dry matter production by the whole community are obtained (Sinclair, 1998). This also promotes improved radiation use efficiency during grain filling, which further contributes to the production of more kernels per plant and higher grain yield (Tollenaar *et al*., 1992).

In a plant density study by Alessi & Power (1975) the dry matter production for short season hybrids in drier years was similar to that of long season hybrids. Optimum plant density for these two parameters was in the range of 30000 to 40000 plant ha^{-1}. Thus low plant density showed less growth stress when water was limiting than did the higher plant density. Increasing plant density increased dry matter production early in the season before water stress developed. The later maturing hybrid with its larger leaves and stem was less tolerant to water stress than the earlier maturing hybrid with fewer leaves and reduced plant stature (Alessi & Power, 1975).

References

AHMADI, M., WIEBOLD, W.J., BEUERLEIN, J.E., ECKERT, D.J. & SCHOPER, J., 1993. Agronomic practices that affect corn kernel characteristics. *Agron. J.* 85, 615-619.

ALDRICH, S.R., SCOTT, W.O. & HOEFT, R.G., 1986. Modern corn production. A and Publ., Champaign, IL.

ALESSI, J. & POWER, J.F., 1974. Effects of plant population, row spacing and variety of dryland corn in the Northern Plains. I. Corn forage and grain yields. *Agron. J.* 66, 316-319

ALESSI, J. & POWER, J.F., 1975. Response of an early maturing maize hybrid to planting date and plant population in the Northern Plains. *Agron. J.* 67, 762-765.

ALDRICH, S.R., SCOTT, W.O. & LENG, E.R., 1975. Modern corn production. 2nd ed., A & L Publications, Champaign, III. Pp 103-117.

ALMEITA, M.L., MEROTTO, D.E. & SANGOI, L., 2000. Incremento na densidade de plantas: uma alternativa para aumentara o rendimento de graos de milho em regioes de curta estacao estival de crescimento. *Ciencia Rural, Santa Maria*. 30, 23-
29.

ANDERSON, M.C., 1996. Stand structure and light penetration. II. A theoretical analysis. *J. Appl. Ecol.* 3, 41-54.

ANDERSON, S.R., LAUER, M.J., SCHOPER, J.B. & SHIBLES, R.M., 2004. Pollination timing effects on kernel set and silk receptivity in four maize hybrids. *Crop Sci*. 44, 464-473.

ANDRADE, F.H., VEGA, C., UHART, S., CIRILO, A., CANTARERO, M. &VALENTINUZ, O., 1999. Kernel number determination in maize. *Crop Sci*. 39, 453-459.

ANDRADE, F.H., CALVINO, P., CIRILO, A. & BARBIERI, P., 2002. Yield response to narrow rows depend on increased radiation interception. *Agron*. *J*. 94, 975-980

ANDRADE, F.H., UHART, S.A. & CIRILO, A., 1993. Temperature affects radiation use efficiency in maize. *Field Crops Res*. 32, 17-25.

ANDRADE, F.H., UHART, S.A. & FRUGONE, M.I., 1993. Intercepted radiation at flowering and kernel number in maize: shade versus plant density effects. *Crop Sci*. 33, 482-485.

ANDRADE, F.H., VEGA, C., UHART, S., CIRILO, A., CANTARERO, M. & VALENTINUZ, O., 1999. Kernel number determination in maize. *Crop Sci*. 39, 453-459.

ARC-GCI, 2002., Maize information guide. ARC-Grain Crop Institute, Potchefstroom, South Africa. Pp. 31-38.

ARC-GCI., 1999. Maize information guide. ARC-Grain Crop Institute, Potchefstroom, South Africa.

ARGENTA, G., SILVA, P.R.F. & SANGOI, L., 2001. Arranjo de plantas emmilho: analise do estado da arte. *Ci*. *Rur*. 31, 1075-1084.

BAGGETT, J. & KEAN, D., 1989. Reduction of plant height by head smut infection in sweet corn cultivars. *Hort Sci*. 24, 497-505.

BALLARE, C.L., SCOPEL, A.L. & SANCHEZ, R.A., 1990. Far-red radiation reflected from adjacent leaves: An early signal of competition in plant canopies. Science (Washington, DC) 247, 329-331.

BASSETTI, P. & WESTGATE, M.E., 1993. Emergence, elongation and senescence of maize silks. *Crop Sci*. 33, 271-275.

BAVEC, F. & BAVEC, M., 2002. Effect of plant population on leaf area index, cob characteristics and grain yield of early maturing maize cultivars. *Europ*. *J*. *Agron*.16, 151-159.

BERGER, J., 1969. Maize production and the manuring of maize. *J. Agric. Res.* 1, 293-302.

BOLLERO, G.A., BULLOCK, D.G. & HOLLINGER, S.E., 1996. Soil temperature and planting date effect on corn yields, leaf area and plant development. *Agron. J.* 88, 385-390.

BOYAT, A., KAAN, F. & PANOUILLE, A., 1990. Adaptation de 4 types varietaux de mais aux fortes densites de peuplement. In: Picard, D. (Ed.), *Physiologie et production du mais*. INRA, Paris, pp. 335-343.

BUREN, L.L., MOCK, J.J. & ANDERSON, I.C., 1974. Morphological and physiological traits in maize associated with tolerance to high plant density. *Crop Sci.* 14, 426-429.

BUREN, L.L., 1970. Plant characteristics associated with barrenness in maize. Ph.D. Thesis. Iowa State University, Ames.

CARCOVA, J. & OTEQUI, M.E., 2001. Ear temperature and pollination timing effects on maize kernel set. *Crop Sci.* 41, 1809-1815.

CARSON, P.L., WARD, R.C., SHANK, D.B. & BEATTY, D.W., 1966. Stable corn yields sought in Northern Great Plains. *Crops Soils Mag.* 19, 297-305.

CHASE, S.S. & NANDA, D.K., 1967. Number of leaves and maturity classification in Zea mays L. *Crop Sci.* 7, 431-432.

CIRILO, A.G & ANDRADE, F.H., 1994. Sowing date and maize productivity: I. Crop growth and dry matter partitioning. *Crop Sci.* 34, 1039-1043.

CORKE, H. & KANNENBERG, L.W., 1989. Selection for vegetative phase and actual filling period duration in short season maize. *Crop Sci.* 29, 607-612.

CROSS, H.Z. & ZUBER, M.S., 1973. Interrelationships among plant height, number of leaves and flowering dates in maize. *Agron. J.* 65, 71-75.

CROSS, H.Z., 1977. Interrelationships among yield stability and yield components of in early maize. *Crop Sci.* 17, 741-745

CROSS, H.Z., 1991. Leaf expansion rate effects on yield and yield components in early maturing maize. *Crop Sci.* 7, 579-583.

CROSS, H.Z., 1990. Selecting for rapid leaf expansion in early-maturing maize. *Crop Sci.* 30, 1029-1032.

DAYNARD, T.B., 1972. Relationships among black layer formation, grain moisture percentage and heat unit accumultion in corn. *Agron. J.* 64, 716-719.

DAYNARD, T.B & MULDOON, J.F., 1983. Plant to plant variability of maize plants grown at different densities. *Can. J. Plant Sci*. 63, 45-59.

DAYNARD, T.B. & KANNENBERG, L.W., 1976. Relationships between length of the actual and effective grain filling periods and the grain yield of corn. *Can. J. Plant Sci*. 56, 237-242.

DAYNARD, D.T. & DUNCAN, W.G., 1972. The black layer and grain maturity in corn. *Crop Sci*. 9, 473-476.

DENNIS, R.E., 1996. Maize for grain in Arizona. Univ. Ariz. Coop. Ext, Tucson

DERIEUX, M., BONHOMME, R., DUBURCQ, J.B. & RUGET, F., 1985. Variations du nombre de grains chez differents genotypes de mais. *Agron. J*. 5, 355-359.

DIJAK, M., MODARRES, A.M., HAMILTON, R.I., DWYER, L.M., STEWART, D.W., MATHER, D.E. & SMITH, D.L., 1999. Leafy reduced-stature maize hybrids for short-season environments. *Crop Sci*. 39, 1106-1110.

DOBBEN, W.H., 1992. Influence of temperature and light conditions on dry matter distribution, development rate and yield in arable crops. *Neth. J. Agric. Sci*. 10, 377-389.

DOWKER, B.D., 1963. Rainfall reliability and maize yields in Machakos district. *East African Agricultural and Forestry Journal*. 28, 134-138.

DU TOIT, A.S., PRINSLOO, M.A., DURAND, W. & KIKER, G., 2002. Vulnerability of maize production to climate change and adaptation in South Africa, Combined Congress: South African Society of Crop Protection and South African Society of Horticultural Science, Pietermaritsburg (SA).

DWYER, L.M. & STEWART, D.W., 1986. Leaf area development in field-grown maize. *Agron. J*. 78, 334-343.

DWYER, L.M., D.W. STEWART, D.D., HAMILTON, R.I. & HOUWING, L., 1992. Ear positioning and vertical distribution of leaf area in corn. *Agron. J*. 84, 430-438.

DUNCAN, W.G., 1958. The relationship between corn population and yield. *Agron. J*. 50, 82-84.

DUNCAN, W.G., 1972. Plant spacing, density, orientation and light relationships as related to different corn genotypes. Reprinted from Proc. 27th Annual Corn and Sorghum Research Conf. Am. Seed Trade Assoc., Washington, DC.

EARLY, E.B., MCIRATH, W.O., SEIF, R.D. & HAGEMAN, R.H., 1987. Effects of shade applied at different stages of plant development on corn (*Zea mayz L*.) production. *Crop Sci*. 7, 151-156.

ECHARTE, L., LUQUE, S., ANDRADE, F.H., SADRAS, V.O., CIRILO, A., OTEQUI, M.E. & VEGA, C.R.C., 2000. Response of maize kernel number to plant density in Argentinean hybrids released between 1965 and 1993. *Field Crop Res*. 68, 1-8.

EDMEADES, G.O., BOLANOS, J., A. ELINGS, A., J.M. RIBAUT, J.M & BANZIGER, M., 2000. The role and regulation of the anthesis-silking interval in maize. In: Westgate, M.E., K.J. Boote (Eds.), Physiology and modeling kernel set in maize. CSSA, Madison, WI. Pp. 43-73.

EDMEADES, G.O., FAIREY, N.A. & DAYNARD, T.B., 1997. Influence of plant density on the distribution of assimilates in maize at flowering. *Can. J. Plant Sci*. 59, 577-584.

EDMEADES, G.O. & LAFITTE, H.R., 1993. Defoliation and plant density effects on maize selected for reduced plant height. *Agron. J*. 84, 430-438.

EDMEADES, G.O., BOLANOS, J, HERNADEZ, M & BELLO, S., 1993. Cause for silk delay in a lowland tropical maize poupulation. *Crop Sci*. 33, 1029-1035.

EDMEADES, G.O. & DAYNARD, T.B., 1979. The relationship between final yield and photosynthesis at flowering in individual maize plants. *Can. J. Plant Sci*. 59, 585-601.

EDWARDS, J.T., PURCELL, L.C. & VORIES, E.D., 2005. Light interception and yield potential of shorts-season maize hybrids in the Midsouth. *Agron. J*. 97, 225-234.

FANCELLI, A.L & DOURADO-NETO, D., 2000. Producao de Milho. *Agropecuaria, Guaiba*.

FARNHAM, D.E., 2001. Row spacing, plant density and hybrid effects on corn grain yield and moisture. *Agron. J*. 93, 1049-1053.

FORTIN, M.C., PIERCE, F.J. & EDWARDS, M., 1994. Corn leaf area response to early season soil temperature under crop residues. *Agron. J*. 86, 355-359.

FRANZKY, K., 1996. Farmers should plant balance varieties to ensure success. *www.garstseed.com*

GARDNER, W.R. & GARDNER, H.R., 1983. Principles of water management under drought conditions. *Agric. Water Manag*. 7, 143-155.

GOSSE, G., VARLET-GRANCHE, C., BONHOMME, R., CHARTIE, M., ALLIRAND, J. & LEMAIRE, G., 1986. Production maximale de matiere seche et rayonnement solaire intercepte par un couvert vegetal. *Agron. J*. 6, 47-56.

GRANT, R.F., JACKSON, B.S., KINIRY J.R. & ARKIN, G.F., 1989. Water deficits timing effects on yield components in maize. *Agron*. *J*. 81, 61-65.

GREEN, T.S., ENDER, M. & MOCK, J.J., 1985. Effect of sowing dates on maize yields. *Agric*. *Sci*. 20, 51-63.

GUPTA, S.C. 1985., Predicting corn planting date for moldboard and no-till tillage systems in the Corn Belt. *Agron*. *J*. 77, 446-455.

GYENES-HEGYI, Z., KIZMUS, L., ZSUBORI, L. & MARTON, L.C., 2002. Plant height and height of the main ear in maize (*Zea mays L*.) at different locations and different plant densities. *Acta Agr*. *Hungarica*. 50, 75-84.

HASHEMI, A.M., HERBERT, S.J. & PUTNAM, D.H., 2005. Yield response of corn to crowding stress. *Agron. J*. 97, 839-846.

HASHEMI-DEZFOULI, A & Herbert, S.J., 1992. Intensifying plant density response of corn with artificial shade. *Agron*. *J*. 84, 547-551.

HALL, A.J., LEMCROFT, J.H. & TRAPANI, N., 1981. Water stress before and during flowering in maize and its effects on yields, its components and their determinants. *Maydica*. 26, 19-38.

HANWAY, J.J., 1989. Defoliation effects on different corn (*Zea mays L*) hybrids as influenced by plant population and stage of development. *Agron*. *J*. 61, 534-538.

HARRIS, R.E., MOLL, R.H. & STUBER, C.W., 1984. Control and inheritance of prolificacy in maize. *Crop Sci*. 16, 843-850

HATFIELD, A.L., BENOIT, G.R & RAGLAND, J.L., 1984. The growth and yield of corn. IV. Environmental effects on grain yield components of mature ears. *Agron*. *J*. 57, 293-295.

HESKETH, J.D. & WARRINGTON, I.J., 1989. Corn growth response temperature: rate and duration of leaf emergence. *Agron*. *J*. 81, 696-701.

HICKS, D.R., HARRINGTON, J.D. & MCGAHEN, J.H., 1993. Maximizing the advantages of early corn planting. National Corn Handbook, Crop Management. Purdue University Cooperative Extension Service. West Lafayette, Indiana. NCH-35.

HICKS, D.R. & R.E. STUCKER, R.E., 1972. Plant density effect on grain yield of corn hybrids diverse in leaf orientation. *Agron*. *J*. 64, 484-487.

HOWELL, T.A., SCHNEITER, A.D. & EVETT, S.R., 1998. Surface and subsurface microirrigation of corn-South High Plains. Trans. ASAE. 40, 635-641.

HUNTER, R.B., 1977. Growing corn and sorghum in short-season areas. In proc. Thirty-second Annu. Corn and Sorghum Res. Conf., Am. Seed Trade Assoc. Washington, D.C.

HUNTER, R.B., 1980. Increased leaf area and yield of maize in short-season areas. *Crop Sci*. 20, 1029-1032.

HUNTER, R.B., 1990. Increased leaf area and yield of maize in short-season areas. *Crop Sci*. 20, 571-574.

HUNTER, R.B., HUNT, L.A. & KANNENBERG, L.W., 1974. Photoperiod and temperature effects on corn. *Can. J. Plant Sci*. 54, 71-78.

JACOBS, B.C. & PEARSON, C.J., 1991. Potential yield of determined by rates of growth and development of ears. *Field Crops Res*. 27, 281-298.

JONES, R.J. & SIMMONS, S.R., 1983; 1986., Effect of altered source-sink ratio on growth of maize kernels. *Crop Sci*. 23, 129-134.

KINIRY, J.R & KNIEVEL, D.P., 1995. Response of maize seed number to solar radiation intercepted soon after anthesis. *Agron. J*. 87, 228-234.

KINIRY, J.R., JONES, C.A., O`TOOLE, J.C., BLANCHET, R., CABELGUENNE, M. & SPANEL, D.A., 1989. Radiation-use efficiency in biomass accumulation prior to grain-filling for five grain crop species. *Field Crops Res*. 20, 51-64.

KINIRY, J.R. & RITCHIE, J.T., 1985. Shade-sensitive interval of kernel number of maize. *Agron. J*. 77, 711-715.

KNOP, K.R. & MASON, S.C., 1985. Kernel breakage and density of normal and opaque-2 maize grain as influenced by nitrogen. *Crop Sci*. 29, 158-163.

KOESTER, R.P., SISCO, P.H. & STUBER, C.W., 1993. Idendification of quantitative trait loci controlling days to flowering and plant height in two near isogenic lines of maize. *Crop Sci*. 33, 1209-1216.

LARSON, E.J. & CLEGG, M.D., 1999. Using corn maturity to maintain grain yield in the presence of late season drought. *J. Prod. Agric*. 12, 400-405.

LAUER, J.G., CARTER, P.R., WOOD, T.M., DIEZEL, G., WIERSMA, D.W., RAND, R.E. & MLYNAREK, M.J., 1999. Corn hybrid response to planting date in the Northern Corn Belt. *Agron. J*. 91, 834-839.

LEJEUNE, P & BERNIER, G., 1996. Effects of environment on the early steps of ear initiation in maize (*Zea mays L*.). *Plant, Cell and Environment*. 19, 217-224.

LEMCOFF, J.H. & LOOMIS, R.S., 1986. Nitrogen influences on yield determination in maize. *Crop Sci*. 26, 1017-1022.

LEWIS, B., 1998. Corn hybrid selection. Pioneer Hi-Bred International, Inc. CCA, American Society of Agronomy.

LOOMIS, R.S. & CONNORS, D.J., 1992. Productivity and management in agricultural systems. Cambridge: Cambridge University, 550-561.

MADDONNI, G.A., OTEGUI, M.E. & BONHOMME, R., 2004. Grain yield components in maize: II. Postsilking growth and kernel weight. *Field Crops Res*. 56, 257-264.

MADDONNI, G.A., OTEGUI, M.E. & BONHOMME, R., 1998. Grain yield components in maize: II. Postsilking growth and kernel weight. *Field Crops Res*. 56, 257-264.

MADDONNI, G.A & OTEGUI, M.E., 1996. Leaf area, light interception and crop development in maize. *Field Crop Res*. 48, 81-87.

MAJOR, D.J., MORRISON, R.J., BLACKSHAW, R.E. & ROTH, B.T., 1991. Agronomy of dryland corn production in the Northern Great Plains. *J. Prod. Agric*. 4, 606-613.

MAJOR, D.J. & DYNARD T.B., 1972. Hyperbolic relation between leaf area index and plant population in corn. *Can. J. Plant Sci*. 52, 112-115.

MODARRRES, A.M., HAMILTON, R.I., DWYER, L.M., DIJAK, M. & SMITH, D.L., 1998. Leafy reduced-staure maize for short-season environments: Population density and planting pattern effect on hybrid perfomance. *Maydica*. 43, 227-234.

MODARRES, A.M., HAMILTON, R.I., DIJAK, M., DWYER, L.M., D.W. STEWART, D.W. & SMITH, D.L., 1998. Plant population density effects of maize inbred lines grown in short season environments. *Crop Sci*. 38,104-108.

MODARRRES, A.M., HAMILTON, R.I., DWYER, L.M., DIJAK, M. & SMITH, D.L., 1997. Leafy reduced-staure maize for short-season environments: Yield and yield components of inbred lines. *Euphytica*. 97, 129-138.

MULDOON, J.F., DAYNARD, T.B., DUINEN, B.V. & TOLLENAAR, M., 1984. Comparisons among rates of appearance of leaf tips, collars and leaf area in maize (*Zea mays L*.). *Maydica*. 29, 109-120.

MONTEITH, J.L., 1981. Does light limit crop production. In C.B. Johnson (ed) Physiological processes limiting crop productivity. Butterworths, London. Pp 23-39.

MONTEITH, J.L., 1977. Radiation and crops. *Exp. Agric*. 1, 241-251.

MORRISON, M.J., STEWART, D.W., MCVETTY, P.B.E., 1992. Maximum area, expansion rate and duration of summer maize leaves. *Can. J. Plant. Sci.* 72, 117-126.

NAFZIGER, E.D., CARTER, P.R. & GRAHAM, E.E., 1994. Response of corn to uneven emergence. *Crop Sci.* 31, 811-815.

NeSMITH, D.S. & RITCHIE, J.T., 1992. Short and long term responses of corn to a pre-anthesis soil water deficit. *Agron. J.* 84, 107-113.

NIELSON, R.L., THOMISON, P.R., BROWN, G.A., HALTER, A.L., WELLS, J. & WUETHRICH, K.L., 2002. Delayed planting date effects on flowering and grain maturation of corn. *Agron. J.* 94, 549-558.

NIELSON, N.J. 1997., An early planted corn. http://www.landecago.com/ehprefgd.pdf

NIELSON, R.L. 1988., Influence of hybrids and plant density on grain yield and stalk breakage in corn grown in 15-inch row spacing. *J. Prod. Agric.* 1, 190-195.

NORWOOD, C.A., 2001. Dryland corn production in Western Kansas: Effect of hybrid maturity, planting date and plant population. *Agron. J.* 93, 540-547.

NRC., 1989. National Research Council. Alternative Agriculture. National Academy Press, Washington, DC. Pp. 98-108.

OKTEM, A. 2000., Determination of sowing dates of corn (*Zea mays L. saccharata Sturt*) under dryland conditions. *Turkish Journal of Agriculture and Forestry*. 21, 65-71.

OLSON, P.J., 1930. Planting rates for early varieties of corn. North Dakota Agr. *Exp. Sta. Cir.* 43, 8-16.

OLSON, R.A. & SANDER, D.H., 1988. Corn production. Pp 639-686. In SPRAQUE, G.F. & DUDLEY, J.W. (ed.) Corn and corn improvement, 3rd ed. *Agron. Monogr.* 18. ASA, Madison, W.I.

OTEGUI, M., 1995. Prolificacy and grain yield components in modern Argentinian maize hybrids. Maydica. 40, 371-376.

OTEGUI, M. & ANDRADE, F.H., 2000. New relationships between light interception, ear growth, and kernel set in maize. In: Westgate, M.E., Boote, K.J. (Eds), Physiology and Modelling kernel set in maize. CSSA, Madison, WI. Pp. 89-102.

OTEGUI, M.E. & MELON, S., 1997. Kernel set and flower synchrony within the ear of maize: I. Sowing date effects. *Crop Sci.* 37, 441-447.

OTEGUI, M.E., NICOLINI, M.G., RUIZ, R.A. & DODDS, P.A., 1995. Sowing date effects on grain yield components for different maize genotypes. *Agron*. *J*. 87, 29-33.

OTTMAN, M.J. & WELCH, L.F., 1989. Planting pattern and radiation interception, plant nutrient concentration and yield in corn. *Agron*. *J*. 81, 167-174.

PEDERSEN, P. & LAUER, J.G., 2002. Influence of rotation sequence on the optimum corn and soybean plant population. *Agron. J*. 94, 968-974.

PEPPER, G.E., 1987. The effect of leaf orientation and plant density on the yield of maize (*Zea mays L*.). Ph.D. Thesis (Diss. Abst. 75-100) Iowa State University, Ames.

PEPPER, G.E., PEARCE, R.B. & MOCK, J.J., 1990. Leaf orientation and yield of maize. *Crop Sci*. 17, 883-886.

RAJCAN, I. & SWANTON, C.T., 2001. Understanding maize-weed competition: resource competition, light quality and the whole plant. *Field Crops Res*. 71, 139-150.

RITCHIE, J.T. & ALAGARSWAMY, G., 2003. Model concepts to express genetic differences in maize yield components. *Crop Sci* 95, 4-9.

RODRIQUEZ, M.S., 1987. Agronomic practices for reducing drought stress and improving maize grain yield in the semi-arid tropics of West Africa. In: *Food Grain Production in Semi-Arid Africa*. Menyonga, J.M., Taye, B. & Youdeoweni, A. (Eds.), pp. 493-510.

RUSSEL, K.W & STUBER, C.W., 1983. Prediction of tassel initiation in corn. *Crop Sci*. 24, 507-510.

SANGOI, L., GRACIETTI, M.A., RAMPAZZO, C. & BIACHETTI, P., 2002. Response of Brazilian maize hybrids from different eras to changes in plant population. *Field Crops Res*. 79, 39-51.

SANGOI, L. & SALVADOR, R.J., 1996. Agronomic performance of male sterile and fertile maize genotypes at two plant populations. Ciencia Rural, Santa Maria. 26, 377-388.

SANGOI, L. & SALVADOR, R.J., 1998. Influence of plant height and leaf number on maize production at high plant densities. Pesquira Agropecuaria Brasileira. Brasilia. 33, 297-306

SANGOI, L., 1993 Aptidao dos campos de langes (SC) para producao de milho em diferentes epocas de semeadura. Pesquira Agropecuaria Brasileira. Brasilia. 28, 51-63

SANGOI, L., GRACIETTI, M.A, RAMPAZZO, C & BIANCHETTI, P., 2002. Response of Brazillian maize hybrids from different eras to changes in plant density. *Field Crop Res*. 79, 39-51.

SALVADOR, R.J. & PEARCE, R.B., 1995. Proposed standard system of nomenclature for maize grain filling events. *Maydica*. 40, 141-146.

SARQUIS, J.I., GONZALEZ, H. & DUNLAP, J.R., 1998. Yield response of two cycles of selection from a semi-prolific early maize (Zea mays L.) population to plant density, sucrose infusion and pollination control. *Field Crop Res*. 55, 109-116.

SCARSBROOK, C.E. & DOSS, B.D., 1972. Leaf area index and radiation as related to corn yield. *Agron. J*. 65, 459-461.

SCHUSSLER, J.R. & WESTGATE, M.E., 1995. Assimilate flux determines kernel set at low water potential in maize. *Crop Sci*. 35, 1074-1080.

SILVA, P.R.F., 1992. Densidade e arranjo de plants em milho. Cientec-Abms. 92, 291-294

SILVA, P.R.F., ARGENTA, G. & REZERA, F., 1998. Resposta de hibridos de milho a densidade de plantas, em tres epocas de semeadura. Ciencia Rural, Santa Maria. 28, 699-706

SINCLAIR, T.R., 1998. Historical changes in harvest index and crop nitrogen accumulation. *Crop Sci*. 38, 638-643.

SHEPERD, L.N., HICKS, D.R. & SCHMIDTH, W.H., 1991. Maximizing the advantages of early corn planting. National Corn Handbook, Crop Management. Purdue University Cooperative Extension Service. West Lafayette, Indiana. NCH-35.

SHAVER, D.L., 1983. Genetics and breeding of maize with extra leaves above the ear. Proc Annu Corn-Sorghum Res Conf. 38, 161-180.

STAGGENBORG, S.A., FJELL, D.L., DELVIN, D.L., GORDON, W.B., MADDUX, L.D. & MARSH, B.H., 1999. Selecting optimum planting dates and plant populations for dryland corn in Kansas. *J. Prod. Agric*. 12, 85-90.

STEWART, D.D. & DWYER, L.M., 1999. Mathematical characterization of leaf shape and leaf area of maize hybrids. *Crop Sci*. 39, 422-427.

STEWART, D.W., DWYER, L.M., ANDREWS, C.J. & DUGAS, J.A., 1997. Modelling carbohydrates production, storage and export in leafy and normal maize. *Crop Sci*. 37, 1228-1236.

STICKLER, F.G., 1984. Row width and plant population studies with corn. *Agron. J*. 56, 438-441.

STINSON, H.T. & MOSS, D.N., 1986. Some effects of shade upon corn hybrids tolerant and intolerant of dense plantings. *Agron. J*. 52:482-484.

SUTTON, L.M. & STUCKER, R.E., 1974. Growing degree days to black layer compared to relative maturity rating of corn hybrids. *Crop Sci*. 14, 408-412.

TAYLOR, H.M. & BLACKETT, P.S., 1982. Soybean and maize yield as affected by row spacing, planting dates and seasonal water supply. *Agron. J*. 80, 930-935.

TETIO-KAGHO, F & GARDNER, F.P., 1988. Response of maize to plant population density. I. Canopy development, light relationships and vegetative growth. *Agron. J*. 80, 930-935.

THIAGARAJAH, M.R., HUNT, L.A. & MAHON, J.D., 1991. Effects of position and age on leaf photosynthesis in corn (*Zea mays L*.). *Can. J. Bot*. 59:28-33.

THIAGARAJAH, M.R. & HUNT, L.A., 1982. Effects of temperature on leaf growth in corn (*Zea mays L*.). *Can. J. Bot*. 60, 1647-1652.

TOKATLIS, I.S. & KOUTROUBAS, S.D., 2004. A review of maize hybrids dependence on high plant populations and its implications for crop yield stability. *Field Crop Res*. 49, 119-126.

TOLLENAAR, M., 1992. Is low plant population a stress in maize? *Maydica*. 37, 305-311.

TOLLENAAR, M. & AGUILERA, A., 1992. Radiation use efficiency of an old and a new maize hybrids. *Agron. J*. 84, 536-541.

TOLLENAAR, M., DWYER, L.M & STEWART, D.W., 1992. Ear and kernel formation in maize hybrids representing three decades of yield improvement in Ontario. *Crop Sci*. 32, 432-438.

TOLLENAAR, A., AGUILERA, A & NISSANK, S.P., 1997. Grain yield is reduced more by weed interference in an old than in a new maize hybrid. *Agron. J*. 89, 239-246.

TOLLENAAR, M. & BRUULSEMA, T.W., 1998. Effects of temperature on rate and duration of kernel dry matter accumulation of maize. *Can. J. Plant Sci*. 68, 935-940.

TOLLENAAR, M., 1997. Sink-source relationship during reproductive development in maize. *Maydica*. 22, 49-75.

TROYER, A.F & Rosenbrook, R.W., 1991. Utility of higher plant densities for corn perfomance testing. *Crop Sci*. 23, 863-867.

TROYER, A.F., 1968. Yield as influenced by maturity and population. Proc. Annu. Hybrid Corn Sorghum Res. Conf. AM. Seed Trade Assoc. 22, 91-98.

VEGA, C.R.C., ANDRADE, F.H. & SADRAS, V.O., 2000. Reproductive partitioning and seed set efficiency in soybean, sunflower and maize. *Field Crop Res*. 72, 165-173.

VEGA, C.R.C., ANDRADE, F.H., SADRAS, V.O., UHART, S. & VALENTINUZ, O.R., 2001. Seed number as a function of growth. A comparative study in soybean, sunflower and maize. *Crop Sci*. 41, 748-754.

VERHAGEN, A.M.W., WILSON, J.H. & BRITTEN, E.J., 1993. Plant production in relation to foliage illumination. *Ann*. *Bot*. 27, 627-640.

WATSON, D.J., 1997. Comparative physiological studies on the growth of field crops: I. Variation in net assimilation rate and leaf area between species and varieties and within and between years. *Ann*. *Bot*. 41, 41-76.

WESTGATE, M.E., 1997. Physiology of flowering in maize: Identifying a venues to improve kernel set during drought. Proceedings of a Symposium, March 25-29, 1996. CIMMYT, El Batam, Mexico. Pp 136-141.

WESTGATE, M.E., FORCELLA, F., REICOSKY, D.C. & SOMSEN, J., 1997. Rapid canopy closure for maize production in the Northern US Corn Belt: Radiation-use efficiency and grain yield. *Field Crops Res*. 49, 249-258.

WIIDAKAS, W., 1958. Is early maturing corn more dependable? North Dakota Farm Res. 20, 4-12.

YOKOZAWA, M. & HARA, T., 1995. Foliage profile, size structure and stem diameter-plant height relationship in crowded corn plant population. *Ann Bot*. 76, 271-285.

CHAPTER 2: GENERAL MATERIAL AND METHODS

AS the material and methods employed at the two experimental sites (Bethlehem and Potchefstroom) were basically the same, they are presented in this chapter. Where differences occurred, they are specified.

2.1. Sites and soil

Experimental field studies were conducted under dryland conditions during the 2004/05 growing season at two agricultural research institutes in the North West and Free State Provinces of South Africa, namely the ARC-Grain Crops Institute at Potchefstroom and the ARC-Small Grain Institute at Bethlehem. The soil type at Potchefstroom was of the Hutton form and at Bethlehem it was the Avalon form (ARC-GCI, 2002). Selected properties of these two soils appear in Table 2.1.

Table 2.1 Selected properties of soil at Potchefstroom and Bethlehem

Locality	Chemical analysis																			
	pH (KCl)		P mg/kg (Bray-1)		K mg/kg (Ambic-1)		Ca mg/kg (Ambic-1)		Mg mg/kg (Ambic-1)		Zn mg/kg (Ambic-1)		NH4$^+$ (N) mg/kg		NO3$^-$ (N) mg/kg		N (%)		Clay (%)	
	Soil depth (cm)																			
	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60
Potchefstroom	6.3	6.6	26.6	10.4	167.7	102.7	1659	1641	546.7	546	8.7	5.9	2.1	2	3.8	6.4	0.1	0.1	30.5	31.8
Bethlehem	5.4	5.5	35.9	22.3	71	64	410	554	410	554	4.5	3.3	0.9	0.9	7.9	5.5	0.03	0.04	8.4	10.1

2.2. Rainfall and temperatures

Rainfall data (Fig 2.1), maximum and minimum temperatures (Table 2.2) recorded during the 2004/05 growing season were compared with the 15 year long-term average at Potchefstroom.

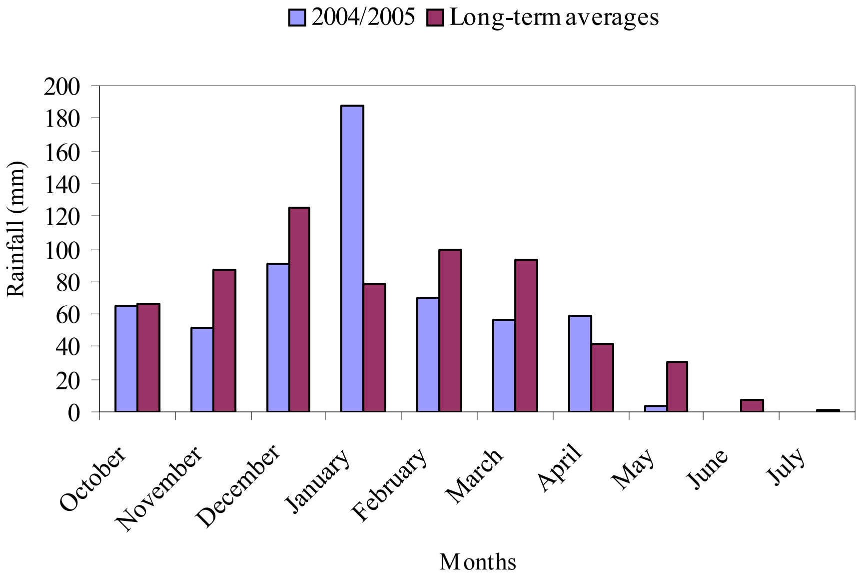

Fig 2.1 Monthly rainfall (mm) from October to July during the 2004/2005 growing season compared with the 15 year long-term averages at Potchefstroom

For Bethlehem, rainfall data are given in Fig 2.2, and maximum and minimum temperatures recorded during the 2004/05 growing season compared with the 15 year long-term averages appear in Table 2.3

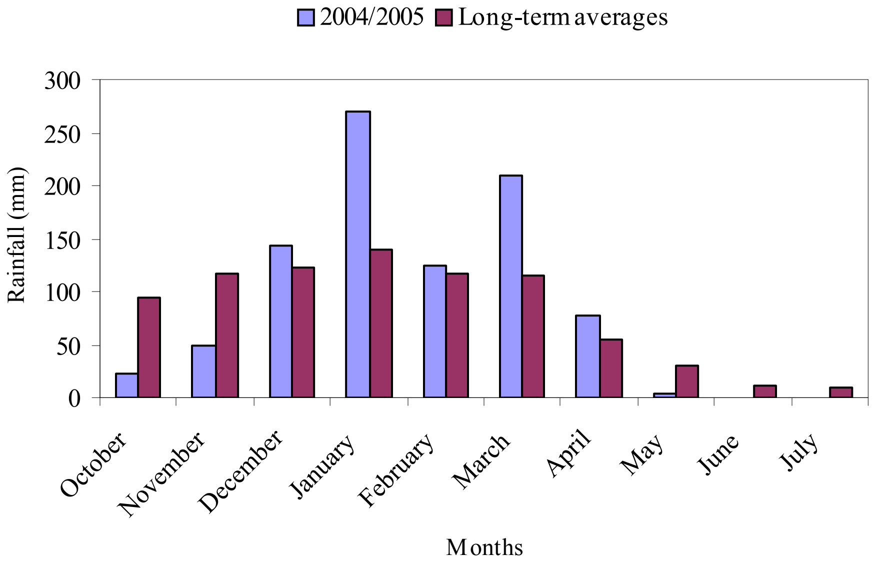

Fig 2.2 Monthly rainfall (mm) from October to July during the 2004/2005 growing season compared with the 15 year long-term averages at Bethlehem

Table 2.3 Mean monthly maximum and minimum temperatures during the 2004/05 growing season compared with the 15 year long-term averages for Bethlehem

	2004/05 season		Long-term averages	
Months	Max °C	Min °C	Max °C	Min °C
October	25.8	8.6	24.4	9.1
November	30.2	12.5	25.3	10.9
December	28.2	14.0	26.2	12.8
January	27.3	15.0	26.4	13.7
February	26.8	14.0	26.2	13.6
March	24.3	11.3	24.6	11.9
April	20.8	7.0	22.2	7.5
May	20.3	1.6	19.1	2.3
June	18.8	-1.1	16.9	-1.2
July	19.4	-2.6	16.4	-1.7

2.3. Experimental design and treatments

At both localities, the experimental design was a randomized complete block (RCB) in split-plot arrangement, with three replications. Three planting dates (early, optimum and late) served as main plot treatment. Three planting densities (low, optimum and high) were assigned as subplot treatments and on sub-subplots there were five cultivars: ENERGY (hybrid, ultra-short cultivar), DKC63-20 (hybrid, ultra-short cultivar), PAN6017 (hybrid, short-cultivar), PHB3203 (hybrid, ultra-short cultivar) and Sam 49 (open-pollinated, short-cultivar). At Potchefstroom, each experimental unit consisted of two rows of 12 m in length at an 1.5 m inter-row spacing. All cultivars were overseeded and thinned after emergence to maintain the following density: Low density (16 000 plants ha^{-1}), optimum (20 000 plants ha^{-1}) and high density (24 000 plants ha^{-1}). The three densities were planted with intra-row spacing of 41.3 cm, 33.33 cm and 27.5 cm, respectively.

Experimental units at Bethlehem consisted of two rows of 10 m in length at an 1.5 m inter-row spacing. Cultivars were overseeded and thinned after emergence to maintain the following densities: Low density (22 962 plants ha^{-1}), optimum (28 700 plants ha^{-1}) and high density (34 440 plants ha^{-1}). For the 3 densities, the final intra-row spacings after thinning were 28.75 cm, 22.98 cm and 19.16 cm, respectively. Early planting at Potchefstroom commenced on 26 October 2004, optimum on 23 November 2004 and late on 4 January 2005. At Bethlehem, early planting was done on 3 November 2004, optimum on 30 November 2004 and late on 5 January 2005.

2.4. Crop husbandry

Seeds were planted by hand planter in 5 cm deep furrows for all treatments at both localities. Weeds were controlled by hand hoeing thrice during the growing period at both localities. Pests, mainly maize stalkborer, were controlled by application of the pesticide Combat at 4 kg ha^{-1}. This granular product was applied manually to the funnels of plants using a container with a perforated lid. It was done once during the growing season for each planting date at both locations. During flowering, Black-spotted maize beetle were controlled by a single application of Methomex 200 SL at 900 ml ha^{-1} for all planting dates at each location. Fertilizer was applied to supplement the N, P and K levels at both locations. At Potchefstroom, 75 kg ha^{-1} 1:0:1 (36) was applied during planting and 108 kg ha^{-1} LAN (28) as top dressing when the maize was at knee height. At Bethlehem, 50 kg ha^{-1} 1:0:1 (36) was applied during planting and 125 kg ha^{-1} LAN (28) as top dressing when the maize was at knee height.

2.5. Data collection

Five plants were sampled from two rows of each plot at the beginning of flowering and 100% flowering for Potchefstroom and Bethlehem during the growing season. Sampled plants were cut off at the ground surface. Plants were separated into leaves and stem for leaf area and dry matter determination. Leaf areas per plant were measured using a leaf area meter, while leaf area index was calculated by dividing leaf area per plant by the sampling area. For dry matter determination, all samples were oven-dried at 65^{o}C for at least 72 hours. Dry biomass of the separated samples was then determined. Physiological maturity was scored as the number of days at which 90% of the plants in an experimental unit had grain moisture content of less than 10 %.

Sixteen plants from two rows were hand harvested at physiological maturity. The cobs were counted, measured, weighed and threshed. Grain yield, kernel number per cob and 100 seed mass were determined. Five plants within each plot were randomly measured to obtain average plant height.

2.6. Statistical analysis

Data were analyzed using the General Linear Model procedure of the Statistical Analysis System (SAS) (SAS Inst., 1996). The Least Significant Difference (LSD) t test was used to compare treatment means at the 0.01 and 0.05% probability levels.

CHAPTER 3: EFFECTS OF PLANTING DATE, PLANT DENSITY AND CULTIVARS ON VEGETATIVE GROWTH OF FIVE SHORT AND ULTRA-SHORT GROWTH CULTIVARS AT BETHLEHEM AND POTCHEFSTROOM

3.1. Introduction

Early planted maize encounters lower soil and air temperatures during the early developmental stages. The low number of thermal units accumulated per day makes such plant to grow slowly (Sangoi, 1993). Generally, early plantings tend to produce short plants that have small individual leaf areas. Aldrich *et al*. (1986) have promoted high plant density as a practice for maximizing yield. Early planted maize also silks earlier in the growing season when the atmospheric evaporative demand is usually smaller (Matzenauer *et al*., 1998), thus decreasing the probability of moisture stress, which can be another reason for early planted maize as higher tolerance of increased plant density. Otegui & Melon (1997) have reported the significant effect of planting dates on final leaf number, and consequently on thermal time, between female bud differentiation and silking. The authors found that fewer numbers of leaves unfolded on plants planted early in the season compared to those planted later. However, Lejeune & Bernier (1996) found that the late maturing genotypes with greater leaf number may require more thermal units prior to tassel initiation**,** and consequently display delayed initiation of reproductive organs in the axillary buds relative to early maturing genotypes.

Planting date effects on intercepted photosynthetically active radiation (PAR) and radiation use efficiency (RUE) were shown in crop dry matter production. Cirilo & Andrate (1994) reported that dry matter accumulation was faster before silking and slower after silking in late plantings compared to the early plantings. Dobben (1992) indicated that increases in temperature during the maize vegetative period accelerated growth rate more than developmental rate, resulting in taller plants with larger total biomass. These results were in agreement with those of Cirilo & Andrade (1994) that crop dry matter partitioning is strongly affected by planting dates, with early planting enhancing reproductive growth and late planting enhancing vegetative growth, as was indicated by the amount of dry matter accumulated before and after silking. In addition, Otegui *et al*. (1995) reported that as planting is delayed, plant growth will occur under high temperatures with concomitant reduction in the duration of crop growth cycle and a reduction in cumulative incident PAR at silking.

Numerous researchers have shown a direct relationship between leaf area index (LAI) and plant density. LAI increases linearly as the plant density increases, but the leaf area per plant decreases as the plant density increases (Begna, 1996). Stewart & Dwyer (1999) reported that the leaf area produced on the main stem of maize plants does not decrease in inverse proportion to an increase in plant density Therefore, when there is little tendency to form tillers, the LAI of a maize canopy can be controlled within wide limits by the density of planting. Discussing factors that influence the leaf area of crops, Bavec & Bavec (2002) mentioned genotype, plant density, climate and soil fertility. Plant density remained the most important factor that influences crop growth and LAI. High plant density increases total light interception by the crop canopy, which convert only 5% of incident solar radiation into chemical energy during the crop-growing season (Begna, 1996). Increasing plant densities could promote utilization of solar radiation by maize canopies (Pepper, 1987). This assumption assumes that water and nutrients will be in limited supply.

Water availability is probably the most important uncontrollable factor affecting optimum plant density of maize under rainfed production systems (Loomis & Connors, 1992). Increasing plant density increases leaf area index and consequently water consumption (Tetio-Kagho & Gardner, 1998). Therefore, the use of high plant density under limited water supply may increase plant water stress and dramatically reduce grain yield, especially if a water shortage coincides with the period of 2-3 weeks bracketing silking (Westgate, 1994). Therefore, the use of short growth season hybrids with short plant height, lower leaf number, upright leaves, smaller tassels and more synchronized floral development could improve maize ability to withstand high plant density without presenting a higher percentage of barren plants (Sangoi, 2001). The use of higher plant densities can enable maize to intercept virtually all the available solar radiation earlier in the season, transforming this energy into storage carbohydrates and other foods in more grains per area. Changes in plant morphology and phenology increase the ability of the whole crop community to utilize available resources through increased plant density (Sangoi, 2001). In addition, plant density has important effects on partitioning of dry matter between vegetative and reproductive sinks.

The objective of this study was to evaluate the effects of planting date, plant density and cultivar on vegetative growth of five short and ultra-short growth cultivars at Bethlehem and Potchefstroom

3.2. Material and methods

The material used and the methodology employed are presented in Chapter 2.

3.3. Results and discussion

3.3.1. Crop establishment

In the 2004/2005 growing season there was good rainfall from December to March at both locations (Figure 2.1). A heavy thunderstorm followed immediately after planting the first trial at Potchefstroom. Thus the plants of the first planting date at Potchefstroom were established under difficult conditions of heavy compaction compared to those at Bethlehem, resulting in poor stand and stunted growth. However, for the other planting dates at both locations the crop establishment was good and vigorous because of relatively high rainfall received from planting throughout the season.

3.3.2. Effect of planting date

3.3.2.1. Leaf area index (LAI)

At Bethlehem, planting date was highly significant for LAI (Table 3.1). Early planting date produced the highest LAI of 2.4, followed by late planting date with**,** 2.1 and optimum planting date obtained the lowest LAI of 1.7 (Table 3.2). These results seemed to contradict findings of Cirilo & Andrade (1994) that delay in planting date reduces the intercepted radiation from emergence to flowering due to decreases in plant growth and LAI. In addition, Sangoi (1993) reported that early-planted maize encounters low soil and air temperature resulting in short plant stature with lower individual leaf number and LAI. The results of Sangoi (1993) are not relevant to the findings of the present study, because early planting date at Bethlehem was in November when the temperatures were high.

Table 3.1 PR>F-values from the analysis of variance for leaf area index, dry matter yield (kg ha^{-1}), plant height (cm), days to flowering (50%) and days to physiological maturity of five maize cultivars at Bethlehem

Treatment Effects	Leaf area index	Dry matter (kg ha^{-1})	Plant height (cm)	Flowering (50%)	Physiological maturity
Planting date	0.0001	0.0001	0.0001	0.0001	0.0001
Plant density	0.0001	0.0001	0.1281	0.2075	0.7969
Pd x Pds	0.2016	0.0750	0.1690	0.1185	0.4671
Cvs	0.0001	0.0001	0.0001	0.0001	0.0001
Pd x Cvs	0.5029	0.0802	0.4718	0.4097	0.8025
Pds x Cvs	0.8766	0.7943	0.4332	0.9840	0.3760
Pd x Pds x Cvs	0.9985	0.1506	0.8797	0.7273	0.7961
CV (%)	18.1	14.9	7.2	2.1	2.4

Pd x Pds = planting date x plant density interaction
Cvs = cultivars
Pd x Cvs = planting date x cultivar interaction
Pds x Cvs = plant density x cultivar interaction
Pd x Pds x Cvs = planting date x plant density x cultivar interaction

Similar to Bethlehem, planting date had highly significant effects on LAI at Potchefstroom (Table 3.3 & 3.4). Late planting date produced the greatest LAI of 2.1, while optimum and early planting dates produced similar LAI of 1.8. Similar results have been obtained by Hesketh & Warrington (1989) who found that high amounts of incident radiation accumulated later in the season, which enhanced leaf appearance and higher LAI. In addition, the high LAI at the late planting date agrees with findings of Thiagarajah & Hunt (1989), which they attributed to high temperature and solar radiation intercepted during early growth stages of crops planted late in the season.

3.3.2.2. Dry matter yield

For dry matter yield, planting date was highly significant at Bethlehem (Table 3.1 & 3.2). The trend for dry matter yield corresponded with that of LAI**,** and early planting date was once again superior with higher dry matter of 6426.4 kg ha^{-1}, followed by late planting with 4783.6 kg ha^{-1}, and optimum planting date produced the lowest dry matter yield of 3994.2 kg ha^{-1}. Higher dry matter yield at early planting date confirms findings of Cirilo & Andrade (1994) who found that early planting produced high dry matter before and after silking, in contrast to late planting that exhibited high dry matter before silking, but which declined afterwards.

At Potchefstroom dry matter yield was also significantly affected by planting date (Table 3.3 & 3.4). Late planting date was superior with dry matter yield of 5464.9 kg ha^{-1}, followed by optimum planting with 3834.7 kg ha^{-1}, whilst early planting gave the lowest dry matter yield of 3178.0 kg ha^{-1}. Andrade *et al.* (1993) found that both early and late planting dates have important effects on maize dry matter partitioning. In general, the late planting dates would result in high crop growth rates during the vegetative period because of high radiation use efficiency (RUE) and high percentage radiation interception, but conversely resulted in low crop growth rates during grain filling because of low RUE and low incident radiation. The inverse holds true for early planting date (Cirilo & Andrade, 1994). Results were in general agreement with those of Sangoi (1993) who found that low dry matter yield from early planting was due to the small number of thermal units accumulated per day, which resulted in plants with lower number of leaves and decreased dry matter production.

3.3.2.3. Plant height

At Bethlehem, planting date was highly significant for plant height (Table 3.1 & 3.2). Early planting date exhibited the highest plant height of 178.4 cm**,** followed by optimum planting date with 151.1 cm, and late planting produced the lowest plant height of 146.1 cm. This contradicts previous investigations that have shown that early planting generally resulted in shorter plants that have lower individual leaf area (Sangoi, 1993). These discrepancies could be speculated because of different conditions, since early planting date at Bethlehem occurred in October when temperatures were already high. Increasing plant density at those conditions is usually necessary to maximize yield (Aldrich *et al*., 1986).

At Potchefstroom, planting date x cultivar interaction effect was significant for plant height (Table 3.3 & 3.4). At optimum planting date, PAN6017 surpassed all cultivars with a mean plant height of 219.0 cm. SAM49 followed with 197.2 cm, while ENERGY, DKC63-20 and Phb3203 produced the lowest values of 175.1 cm, 172.2 cm and 172.7 cm, respectively.

Table 3.2 Effect of planting date on leaf area index, dry matter yield (kg ha^{-1}), plant height (cm), days to 50% flowering and days to physiological maturity of five cultivars at Bethlehem

	Cultivars					
Planting date	PAN6017	DKC63-20	Phb3203	SAM49	ENERGY	Mean
			Leaf area index			
Early	2.6a	2.3abc	2.7a	2.1bc	2.4ab	2.4a
Optimum	2.3abc	1.3e	1.9cd	1.4e	1.4e	1.7c
Late	2.6a	1.9cd	2.6a	1.6de	1.6de	2.1b
Mean	2.5a	1.8b	2.4a	1.7b	1.8b	
			Dry matter yield (kg ha^{-1})			
Early	6677.8a	6116.2ab	6657.0a	6125.7ab	6555.3a	6426.4a
Optimum	5150.4cd	3294.6h	4387.9efg	3700.7gh	3437.2h	3994.2c
Late	5755.3bc	4545.5def	5098.4cde	4246.3fg	4272.3fg	4783.6b
Mean	5861.2a	4652.1c	5381.1b	4690.9c	4754.9c	
			Plant height (cm)			
Early	186.8a	172.8c	174.3bc	174.7bc	183.6ab	178.4a
Optimum	157.4d	148.6def	139.9f	154.3de	155.4d	151.1b
Late	156.2d	142.9f	143.2f	144.2ef	144.0f	146.1c
Mean	166.8a	154.7c	152.5c	157.7bc	161.0ab	
			Days to flowering (50%)			
Early	72.1c	67.0e	72.2c	72.0c	66.7e	70.0c
Optimum	75.0b	70.1d	74.4b	74.9b	70.2d	72.9b
Late	78.3a	74.7b	79.2a	78.0a	74.8	77.0a
Mean	75.1a	70.6b	75.3a	75.0a	70.6b	
			Days to physiological maturity			
Early	186.4b	179.3f	185.6bc	186.4b	179.2f	183.4b
Optimum	191.9a	185.1bcd	192.3a	192.6a	185.2bc	189.4a
Late	184.2cde	176.8g	183.8de	183.2e	177.0g	181.0c
Mean	187.5a	180.4b	187.2a	187.4a	180.5b	

Means within a column followed by different letters are significantly different at $P \leq 0.05$ and 0.01

Table 3.3 PR>F-values from the analysis of variance for leaf area index, dry matter yield (kg ha^{-1}), plant height (cm), days to flowering (50%) and days to physiological maturity of five maize cultivars at Potchefstroom

Treatment Effects	Leaf area index	Dry matter yield (Kg ha^{-1})	Plant height (cm)	Flowering (50%)	Physiological maturity
Planting date	0.0002	0.0001	0.0001	0.0001	0.0001
Plant density	0.0001	0.0001	0.0008	0.0001	0.0765
Pd x Pds	0.8916	0.0010	0.6346	0.0792	0.0815
Cvs	0.0001	0.0001	0.0001	0.0001	0.0001
Pd x Cvs	0.1326	0.6887	0.0027	0.0752	0.0001
Pds x Cvs	0.7168	0.2905	0.8279	0.1159	0.0001
Pd x Pds x Cvs	0.2885	0.8116	0.8919	0.5720	0.7923
CV (%)	17.1	15.2	7.3	2.1	2.3

Pd x Pds = planting date x plant density interaction

Cvs = cultivars

Pd x Cvs = planting date x cultivar interaction

Pds x Cvs = plant density x cultivar interaction

Pd x Pds x Cvs = planting date x plant density x cultivar interaction

Table 3.4 Effect of planting date on leaf area index, dry matter yield (kg ha^{-1}), plant height (cm), days to flowering (50%) and days to physiological maturity of five cultivars at Potchefstroom

	Cultivars					
Planting date	PAN6017	DKC63-20	Phb3203	SAM49	ENERGY	Mean
			Leaf area index			
Early	2.5a	1.6cd	2.1ab	1.4d	1.6d	1.8b
Optimum	2.1abc	1.7bcd	2.2ab	1.6cd	1.6d	1.8b
Late	2.5a	2.3ab	2.3a	1.8bcd	1.8bcd	2.1a
Mean	2.4a	1.9b	2.2a	1.6c	1.7c	
			Dry matter yield (kg ha^{-1})			
Early	3469.7ef	2965.3f	3838.7de	2693.8g	2922.3fg	3178.0c
Optimum	4074.3d	3801.1de	3970.8de	3813.8de	3513.8def	3834.7b
Late	5758.7a	5390.9abc	5910.8a	5172.0bc	5092.3c	5464.9a
Mean	4434.2a	4052.4b	4573.4a	3893.2b	3842.8b	
			Plant height (cm)			
Early	184.4cd	162.3fgh	167.4efgh	169.1efg	165.9efgh	169.8b
Optimum	219.0a	172.2ef	172.7ef	197.2b	175.1de	187.2a
Late	188.0bc	149.6i	156.2hi	157.7ghi	164efgh	163.1c
Mean	197.1a	161.4d	165.4cd	174.7b	168.3bc	
			Days to flowering (50%)			
Early	67.6b	61.2bc	66bc	65.7bc	61.7bc	64.4a
Optimum	63.7bc	64.6bc	64.3bc	70.7a	57.4c	69.1c
Late	70.3b	63.6bc	67.9b	67.8b	63.8bc	66.7b
Mean	67.2d	63.1b	66.1c	76.4e	61.0a	
			Days to physiological maturity			
Early	170.3de	163.0h	171.4cd	169.8ef	162.3h	167.4b
Optimum	179.6a	171.9c	177.4b	179.8a	171.6cd	176.0a
Late	171.3cd	162.1h	167.6g	168.7fg	162.1h	166.4c
Mean	173.7a	165.7d	172.1c	172.7b	165.3d	

Means within a column followed by different letters are significantly different at $P \leq 0.05$ and 0.01

3.3.2.4. Days to 50% flowering

For days to 50% flowering, planting date was highly significant at Bethlehem (Table 3.1 & 3.2). Plants established early flowered at 70.0 days after planting, followed by optimum planting date at 73.0 days and late planting flowered 77.0 days after planting. At Potchefstroom, planting date was highly significant for flowering (Table 3.3 & 3.4). Plants of the early planting date flowered at 64.4 days after planting, followed by those of late planting date at 66.7 days**,** whilst optimum planting date exhibited flowers at 69.1 days after planting. These findings were in general agreement with results of Matzenauer *et al*. (1998), who found that early planted maize flowers earlier in the growing season when the atmospheric evaporative demand is usually smaller, thus decreasing the probability of moisture stress.

3.3.2.5. Days to 50% physiological maturity

Planting date was highly significant for days to physiological maturity at Bethlehem (Table 3.1 & 3.2). Plants established late reached physiological maturity at 181.0 days after planting, followed by those planted early at 183.4, whilst those of optimum planting date reached maturity at 189.4 days after planting. These results seemed to contradict the findings of Tollenaar & Aguilera (1992), who reported that late planting date reduced cumulative intercepted PAR from silking to physiological maturity, mainly because of their low values of daily incident radiation.

At Potcheftsroom, planting date x cultivar interaction was highly significant for physiological maturity (Table 3.3 & 3.4). At optimum planting date, DKC63-20 and Energy reached physiological maturity earlier than the other cultivars. At early planting date the trend was similar to that at optimum, with DKC63-20 and Energy reaching physiological maturity earlier than other cultivars. The trend did not change at late planting date and once again DKC63-20 and ENERGY reached physiological maturity earlier than the other cultivars. For PAN6017, DKC63-20, SAM49 and ENERGY there was no significant difference between early and late planting dates, but for all four these cultivars optimum planting date required significantly more days for physiological maturity to be reached. Phb3203 showed significant difference between planting dates.

Late planting caused physiological maturity to be reached earlier at 167.6 days, followed by early planting date at 171.4 days, whereas plants at the optimum planting date reached the physiological maturity stage the latest at 177.4 days after planting.

3.3.3. Effect of plant densities

3.3.3.1. Leaf area index (LAI)

At Bethlehem, plant density was highly significant for LAI (Table 3.1 & 3.5). Plants planted at optimum plant density exhibited highest mean LAI of 2.4, followed by low plant density with 2.1, while those at high plant density produced the lowest LAI of 1.6. Previous findings showed the relationship between LAI and plant density to be generally positive as density increases until optimum, but at the expense of LAI per plant, which decreases as plant density increases (Stewart & Dwyer, 1999; Bavec & Bavec, 2002). One way to increase LAI is to increase plant density (Olson & Sander, 1988). Alessi and Power (1975) studied early maturing maize hybrids in the northern regions of the great plains and found that increasing plant density up to 74 000 plants ha^{-1} produced LAIs as high as 4.9, although this was dependent on hybrid and season. While single-plant yield decreases with increased plant density, total light interception by the canopy is increased (Begna, 1996).

At Potchefstroom plant density caused highly significant differences in LAI (Table 3.2 & 3.6). The trend for the LAI at Potchefstroom was similar to that at Bethlehem, with optimum plant density once again attaining the greatest LAI of 2.2, followed by low plant density with 1.9, while high plant density produced the lowest LAI of 1.5 (Table 4.6). Stickler (1984) found that leaf area per plant decreased from 2300 cm^{-2} at 39500 plants ha^{-1} to 2150 cm^{-2} at 59500 plants ha^{-1}.

Table 3.5 Effect of plant density on leaf area index, dry matter yield (kg ha^{-1}), plant height (cm), days to flowering (50%) and days to physiological maturity of five cultivars at Bethlehem

	Cultivars					
Planting density	PAN6017	DKC63-20	Phb3203	SAM49	ENERGY	Mean
			Leaf area index			
Low	2.7a	1.9bcd	2.4ab	1.8cde	1.9bcd	2.1b
Optimum	2.8a	2.1bc	2.8a	2.0bc	2.1bc	2.4a
High	1.9bc	1.5de	1.8bcd	1.3e	1.3e	1.6c
Mean	2.4a	1.8b	2.3a	1.7b	1.7b	
			Dry matter yield (kg ha^{-1})			
Low	6356.3ab	5089.2def	5797.8bcd	5370.4def	5286.2def	5579.9b
Optimum	7039.9a	5702.5bcde	6246.4bc	5595.3cde	5492.2def	6015.3a
High	4984.4efg	3961.8h	4896.2fg	3904.0h	4283.5gh	4405.9c
Mean	6126.9a	4917.8c	5646.8b	4956.6c	5020.6c	
			Plant height (cm)			
Low	176.9a	155.6de	156.9de	171.3ab	164.2bcd	165.0a
Optimum	165.1bc	158.6bcde	154.7de	157.9bcde	167.7ab	159.8b
High	162.4bcd	154.1de	151.9e	158.2bcde	156.1cde	156.5b
Mean	168.1a	156.1c	154.5c	162.5ab	162.7ab	
			Days to flowering (50%)			
Low	75.2a	70.4b	75.6a	74.8a	70.8b	73.4a
Optimum	74.9a	70.6b	75.0a	74.6a	70.0b	73.0a
High	75.3a	70.7b	75.3a	75.6a	70.9b	73.6a
Mean	75.1a	70.5b	75.3a	75.0a	70.6b	
			Days to physiological maturity			
Low	183.1bc	175.1c	181.6bc	188.0a	178.2c	181.2a
Optimum	187.4ab	183.4bc	187.6ab	186.6b	185.6b	185.9a
High	187.3ab	180.7c	186.4b	187.7ab	180.7c	184.5a
Mean	185.9a	179.7b	185.2a	186.9a	181.5b	

Means within a column followed by different letters are significantly different at $P \leq 0.05$ and 0.01

Table 3.6 Effect of plant density on leaf area index, dry matter yield (kg ha^{-1}), plant height (cm), days to flowering (50%) and days to physiological maturity of five cultivars at Potchefstroom

	Cultivars					
Plant density	PAN6017	DKC63-20	Phb3203	SAM49	ENERGY	Mean
			Leaf area index			
Low	2.4ab	1.7c	2.2b	1.6cd	1.7c	1.9b
Optimum	2.6a	2.3b	2.5ab	1.8c	1.8c	2.2a
High	1.8c	1.4de	1.7cd	1.3e	1.3e	1.5c
Mean	2.2a	1.8bc	2.1a	1.5c	1.6c	
			Dry matter yield (kg ha^{-1})			
Low	4527.2cd	4408.1cd	4419.7cd	3988.2de	3963.4de	4261.3a
Optimum	4196.4b	3904.9bc	4858.8a	3608.9bc	3601.2bc	4034.0b
High	3599.1ef	2864.3g	3461.7efg	3102.5fg	2983.8g	3202.3c
Mean	4107.5a	3725.8b	4246.7a	3566.5b	3516.1b	
			Plant height (cm)			
Low	172.8a	132.5def	136.8cde	147.0bc	142.8bcd	146.4a
Optimum	168.5a	141.8bcde	142.6bcd	152.8b	142.9bcd	149.7a
High	165.3a	127.0f	131.1ef	139.8cde	134.7def	139.6b
Mean	168.9a	133.8d	136.8cd	146.5b	140.1bc	
			Days to flowering (50%)			
Low	69.8b	64.6b	67.9b	69.8b	63.3b	67.1b
Optimum	67.7b	63.1b	66.8b	68.6b	61.8b	65.6a
High	71.3b	67.2b	67.8b	73.4b	64.8b	68.9b
Mean	69.6b	65.0d	67.5c	71.0a	63.0e	
			Days to physiological maturity			
Low	173.9a	166.2e	171.8cd	173.4ab	165.1e	170.1b
Optimum	172.0ab	166.4e	171.7d	173.2ab	166.0e	169.9b
High	173.7ab	165.0e	173.1bc	172.6d	166.1e	170.3b
Mean	173.2a	165.7d	172.1c	172.7b	165.3d	

Means within a column followed by different letters are significantly different at $P \leq 0.05$ and 0.01

3.3.3.2. Dry matter yield

Plant density was highly significant for dry matter yield at Bethlehem (Table 3.2 & 3.5). Plants established at optimum plant density attained higher dry matter yield of 6015.3 kg ha^{-1}, followed by those of low plant density with 5579.9 kg ha^{-1}, whilst high density obtained the lowest dry matter yield of 4405.9 kg ha^{-1}. Previous investigations on the effect of plant density on dry matter yield have shown decreased dry matter for plants grown under high plant density (Alessi & Power, 1975; Otequi, 1997). They ascribed low dry matter production at high plant density to interplant competition for water, nutrients and sunlight.

At Potchefstroom, plant density was also highly significant for dry matter yield (Table 3.3 & 3.6). Plants planted at low plant density was superior with dry matter yield of 4261.3 kg ha^{-1}, followed by those of optimum plant density with 4034.0 kg ha^{-1}, whilst high plant density produced the lowest dry matter yield of 3202.3 kg ha^{-1}. Signs of water stress were noticed under high plant density, whereas there was no observable stress at low and optimum plant densities. These results confirm findings of Alessi & Power (1975) that low and optimum plant density showed less stress when water was limiting while high plant density did show some water stress, which resulted in stunted growth and low dry matter production. However, Tollenaar *et al*. (1997) found that high plant density increases dry matter production under optimum growing conditions, but tend to decrease as water and nutrient stress occur.

3.3.3.3. Plant height

Plant density had a highly significant effect on plant height at Bethlehem (Table 3.1 & 3.5). Low plant density produced the tallest plants of 165.0 cm, while optimum and high plant density produced plants of similar height, 159.8 and 156.5 cm, respectively. These results contradicted findings of Begna (1996), who found higher plant height under high plant density. Gardner *et al*. (1985) found that increased plant density causes plant stems to become thinner and often taller. Borojevic (1990) reported that reductions in plant height may cause more resistance to lodging, and when planted at high plant density, more nutrient uptake occurs, resulting in higher yields per unit area. Height reductions can occur through a shortening of each internode and as a result of changed partitioning within the shoot, whereby the assimilates saved by stem reductions are translocated to ear development.

At Potchefstroom, plant density was highly significant for plant height (Table 3.3 & 3.6). Optimum and low plant density, although statistically similar, were superior with highest plant heights of 149.7 and 146.4 cm, respectively, whereas highest plant density resulted in the lowest plant height of 139.6 cm. Results confirm those of Boyat *et al*. (1990) who found that plant height decreased with an increase in plant density because of mutual shading of plants, acceleration of leaf senescene and decreases in intercepted solar radiation.

3.3.3.4. Days to 50% flowering

At Bethlehem, plant density did not affect days to 50% flowering significantly (Table 3.1). Plant density was highly significant for days to 50% flowering at Potchefstroom, (Table 3.3 & 3.6). Optimum plant density caused plants to reach days to 50% flowering much earlier than those at low and high plant densities.

3.3.3.5. Days to 50% physiological maturity

For days to physiological maturity, plant density was non-significant at both Bethlehem and Potchefstroom (Table 3.1 & 3.3).

3.3.4. Cultivar effect

3.3.4.1. Leaf area index (LAI)

At Bethlehem, cultivar effect was highly significant for LAI (Table 3.1 & 3.2). PAN6017, although statistically similar to Phb3203, was most prolific with a LAI of 2.5, while DKC63-20, SAM49 and ENERGY produced similar LAI of 1.8, 1.7 and 1.8, respectively.

At Potchefstroom, cultivar effect also had a significant effect on LAI (Table 3.3 & 3.4). PAN6017 and Phb3203, although similar, produced the highest LAI of 2.4 and 2.2, DKC63-20 followed with 1.9 while, Sam49 and Energy produced the lowest LAI of 1.6 and 1.7, respectively.

3.3.4.2. Dry matter yield

At Bethlehem, cultivar was highly significant for dry matter yield (Table 3.1). PAN6017 out-yielded all the cultivars with average dry matter yield of 5861.2 kg ha^{-1}, followed by Phb3203 with 5381.1 kg ha^{-1}, while ENERGY, SAM49 and DKC63-20 attained the similar values of 4754.9 kg ha^{-1}, 4690.9 kg ha^{-1} and 4652.1 kg ha^{-1}, respectively (Table 3.2). Cultivar effect was significant for dry matter yield at Potchefstroom (Table 3.3 & 3.4). PAN6017 and Phb3203 produced highest dry matter yield of 4434.2 and 4573.4 kg ha^{-1}, while DKC63-20, SAM49 and ENERGY obtained similar lowest dry matter of 4052.4, 3893.2 and 3842.8 kg ha^{-1}, respectively.

3.3.4.3. Plant height

Cultivars were highly significant for plant height at Bethlehem (Table 3.1 & 3.2). PAN6017 and ENERGY produced the highest values of 166.8 and 161.8 cm, followed by SAM49, DKC63-20 and Phb3203 with similar values of 157.7, 154.7 and 152.5 cm, respectively.

3.3.4.4. Days to 50% flowering

At Bethlehem, cultivar was highly significant for days to 50% flowering (Table 3.1 & 3.2). DKC63-20 and ENERGY reached days to 50% flowering earlier at 70.6 days after planting. However, PAN6017, PHB3203 and SAM49 reached days to 50% flowering at 75.1, 75.3 and 75.0 days after planting. DKC63-20 and ENERGY reached 50% flowering much earlier than other cultivars because they are ultra-short growth season cultivars. Cultivar effect was significant for flowering at Potchefstroom (Table 3.3 & 3.4). ENERGY flowered at 61.0 days after planting, followed by DKC63-20 at 63.1, Phb3203 at 66.1, PAN6017 at 67.2 and SAM49 at 76.4 days after planting, respectively.

3.3.4.5. Days to physiological maturity

At Bethlehem, cultivars caused significant differences in days to physiological maturity (Table 3.1 & 3.2). The trend for all cultivars corresponded with that of days to flowering and once again Energy and DKC63-20, although similar, reached physiological maturity stage early at 180.4 and 180.5 days after planting, while PAN6017, SAM49 and Phb3203 reached physiological maturity stage later at 187.5, 187.4 and 187.2 days after planting.

3.3.4.6. Conclusions

Late planting date attained greater LAI and dry matter yield than optimum and early planting dates at Potchefstroom. In contrast, early planting date at Bethlehem attained the highest LAI and dry matter yield compared to optimum and late planting dates. Cultivars, PAN6017 and Phb3203 produced the highest LAI and dry matter yield at both localities, while SAM49 produced the lowest. However, to generalize these findings, more research over a wider range of locations and seasons should be conducted. Results also indicated that the two locations differed in terms of days to 50% flowering and physiological maturity stages. These differences between the two localities are because plants of the early planting date reached 50% flowering and physiological maturity much earlier at Potchefstroom than at Bethlehem. Late planting date plants at Potchefstroom flowered at the same time as those of the optimum planting date at Bethlehem. DKC63-20 and ENERGY reached the days to 50% flowering and physiological maturity earlier than PAN6017, SAM49 and Phb3203, respectively. This might be as a result of differences in heat units and rainfall distribution between the two locations. Therefore, these environmental factors should be investigated and compared before any recommendations can be made to farmers in particular areas.

References

ALDRICH, S.R., SCOTT, W.O. & HOEFT, R.G., 1986. Modern corn production. 2 ed. Champaign, IL. Pp 357

ALESSI, J. & POWER, J.F., 1975. Response of an early maturing maize hybrid to planting date and plant population in the Northern Plains. *Agron. J.* 67, 762-765.

ANDRADE, F.H., UHART, S.A. & CIRILO, A., 1993. Temperature affects radiation use efficiency in maize. *Field Crops Res*. 32, 17-25.

BAVEC, F. & BAVEC, M., 2002. Effect of plant population on leaf area index, cob characteristics and grain yield of early maturing maize cultivars. *Europ*. *J*. *Agron*.16, 151-159.

BEGNA, S.H., 1996. Effect of population density on the vegetative growth of leafy reduced-stature maize in a short-season area. *J*. *Agron*. *Crop Sci*. 12, 70-83

BOROJEVIC, S., 1990. Genotype-environment interactions for leaf area parameters and yield components and their effect on wheat yield. *Crop Sci*. 22, 1020-1025.

BOYAT, A., KAAN, F. & PANOUILLE, A., 1990. Adaptation de 4 types varietaux de mais aux fortes densites de peuplement. In: Picard, D. (Ed.), *Physiologie et production du mais*. INRA, Paris, pp. 335-343.

CIRILO, A.G & ANDRADE, F.H., 1994. Sowing date and maize productivity: I. Crop growth and dry matter partitioning. *Crop Sci*. 34, 1039-1043.

DAUGHTRY, C.ST., GALLO, K.P & BAUER, M.E., 1983. Spectral estimates of solar radiation intercepted by corn canopies. *Agron*. *J*. 72, 527-531.

DOBBEN, W.H., 1992. Influence of temperature and light conditions on dry matter distribution, development rate and yield in arable crops. *Neth*. *J*. *Agric*. *Sci*. 10, 377-389.

GARDNER, F.P., PREARCE, R.B & MITCHELL, R.L., 1985. Physiology of crop plants. Iowa State University. Press, Ames, Iowa.

HESKETH, J.D. & WARRINGTON, I.J., 1989. Corn growth response temperature: rate and duration of leaf emergence. *Agron*. *J*. 81, 696-701.

LEJEUNE, P & BERNIER, G., 1996. Effects of environment on the early steps of ear initiation in maize (*Zea mays L*.). *Plant*, *Cell and Environment*. 19, 217-224.

LOOMIS, R.S. & CONNORS, D.J., 1992. Productivity and management in agricultural systems. Cambridge: Cambridge University, 550-561.

MATZENAUER, R., BERGAMASCHI, H & BERLATO, M., 1998. Evapotranspiracao da cultura do milho. Revista Brasileira de Agrometeorolgia. Santa. 6, 9-14

OTEQUI, M., 1997. Kernel set and flower synchrony within the ear of maize: II. Plant population effects. *Crop Sci*. 37, 448-455.

OTEGUI, M.E. & MELON, S., 1997. Kernel set and flower synchrony within the ear of maize: I. Sowing date effects. *Crop Sci*. 37, 441-447.

OTEGUI, M.E., 1995. Prolificacy and grain yield components in modern Argentinean maize hybrids. *Maydica*. 40, 371-376.

OLSON, R.A. & SANDER, D.H., 1988. Corn production. Pp 639-686. In SPRAQUE, G.F. & DUDLEY, J.W. (ed.) Corn and corn improvement, 3rd ed. *Agron*. *Monogr*. 18. ASA, Madison, W.I.

PEPPER, G.E., 1987. The effect of leaf orientation and plant density on the yield of maize (*Zea mays L*.). Ph.D. Thesis (Diss. Abst. 75-100) Iowa State University, Ames.

SANGOI, L., 1993 Aptidao dos campos de langes (SC) para producao de milho em diferentes epocas de semeadura. Pesquira Agropecuaria Brasileira. Brasilia. 28, 51-63

SANGOI, L., 2001. Understanding plant density effects on maize growth and development: an important issue to maximize grain yield. Ci. Rur. 31, 159-168.

STEWART, D.D. & DWYER, L.M., 1999. Mathematical characterization of leaf shape and leaf area of maize hybrids. *Crop Sci*. 39, 422-427.

STICKLER, F.G., 1984. Row width and plant population studies with corn. Agron. J. 56, 438-441.

TETIO-KAGHO, F & GARDNER, F.P., 1988. Response of maize to plant population density. I. Canopy development, light relationships and vegetative growth. *Agron*. *J*. 80, 930-935.

THIAGARAJAH, M.R. & HUNT, L.A., 1989. Effects of temperature on leaf growth in corn (*Zea mays L*.). *Can*. *J*. *Bot*. 60, 1647-1652.

TOLLENAAR, M. & AGUILERA, A., 1992. Radiation use efficiency of an old and a new maize hybrids. *Agron*. *J*. 84, 536-541.

TOLLENAAR, A., AGUILERA, A & NISSANK, S.P., 1997. Grain yield is reduced more by weed interference in an old than in a new maize hybrid. Agron. J. 89, 239-246.

WESTGATE, M.E., 1994. Physiology and determination of crop yield. Amer. Soc. Agron. 15, 361-364.

CHAPTER 4: EFFECT OF PLANTING DATE, PLANT DENSITY AND CULTIVARS ON YIELD AND YIELD COMPONENTS OF SHORT AND ULTRA-SHORT GROWTH CULTIVARS AT BETHLEHEM AND POTCHEFSTROOM

4.1. Introduction

Within the grass family, maize is likely the species that presents the highest grain yield potential. In order to fully explore its capacity to transform solar radiation into grain production, it is necessary to understand how plants interact morphologically and physiologically in a community. Another requirement is to identify management practices, which allow crop plants to maximize the use of growth resources in their environment (Anda & Loke, 2005).

Planting date is one of the most important components of a maize cropping system that can influence grain yield and yield components significantly (Ahmadi *et al*., 1993). All other factors being constant, early-planted maize usually requires a higher population to maximize yield, particularly in temperate and sub-tropical regions of the world (Aldrich *et al*., 1986; Anderson, 1995). For optimum production, seed must be planted at the proper time since considerable yield reduction can occur if the crop is planted too early or too late (Chaudry, 1994). According to Khan *et al*. (2002), many factors are responsible for low yield of maize, and one of the most important factors contributing to yield reduction is the planting of maize either too early or too late. The authors concluded that a delay in planting date decreased grain yield by 58.2% and also resulted in lower grain mass and number of grain per ear. Otequi *et al*. (1995) found that early and intermediate planting dates tended to allow plants to best utilize solar radiation, thus resulting in higher grain yield, provided growth factors such as water and nutrient supply were optimal.

Bollero *et al*. (1996) mentioned that the yield differences between planting dates could be related to leaf area development. They found grain yield to decrease linearly with decreasing soil temperature, which affected leaf area development. They reported that increased grain yield with increasing soil temperature could be attributed to a larger leaf area index. Otegui & Melon (1997) reported that delayed plantings are generally accompanied by increased temperatures during the growing season, which accelerate crop development and decrease accumulated solar radiation, resulting in less biomass production, kernel set and grain yield.

Plant density is one of the most important cultural practices determining grain yield, as well as other important agronomic attributes of this crop (Dwyer *et al*., 1994). Plant density has been recognized as a major factor determining the degree of competition between plants (Hashemi *et al*., 2005). Yield per plant decreases as the density per unit area increases. The rate of yield decrease is in response to decreasing light and other environmental resources available to each plant. Yield per plant is also affected by soil fertility (McCullough *et al*., 2000), planting date (Cirilo & Andrade, 1994; Nafziger, 1994), level of water availability (Schussler & Westgate, 1995), and genotype (Modarres *et al*., 1998). Reduction in yield is mostly due to lower number of ears (barrenness) (Hashemi-Dezfouli & Herbert, 1992), fewer kernels per ear (Cox, 1996), lower kernel mass (Hashemi-Dezfouli & Herbert, 1992) or a combination of these components. At high plant density, many kernels may not develop. This occurs in some genotypes due to poor pollination resulting from delayed silking period compared with tassel emergence (Otequi, 1997)**,** and or due to a limitation in assimilate supply that cause**s** kernel and ear abortion (Zinselmeier *et al*., 1995).

At low plant densities, the inadequate number of plants, and therefore ears**,** limits grain yields, whereas at high plant densities, yield declines mostly because of an increase in the number of aborted kernels and barren stalks (Hashemi *et al*., 2005). Identifying the optimum densities that produce the maximum yield per unit area under different environmental conditions and for different genotypes has been the major concern in many investigations. Tollenaar (1978) concluded that hybrids developed in recent years are able to tolerate higher degrees of crowding stress than older genotypes, mainly because of lower lodging frequencies.

In this Chapter results for yield and yield components from the field experiments conducted at Bethlehem and Potchefstroom are presented and discussed.

4.2. Material and Methods

The material used and the methodology employed are presented in Chapter 2.

4.3. Results and discussion

4.3.1. Effect of planting dates

4.3.1.1. Cob number

For cob number, planting date was highly significant at Bethlehem (Table 4.1). Plants established late produced lower cob number, which were 15.5 and 11.5% less than those of optimum and early planting dates (Table 4.2). Harris *et al*. (1984) and Otegui & Melon (1997) found that variation in planting dates influenced the number of grains per ear and number of cobs per plant. The authors reported higher cob number per plant for maize planted earlier in the season than maize planted later in the season. Similar to Bethlehem, the cob number at Potchefstroom was significantly affected by planting date (Table 4.3). Maize at optimum planting date attained higher number of cobs, which was 30.2 and 32.2% more than those of early and late planting dates, respectively (Table 4.4).

4.3.1.2. Cob length

At Bethlehem, the planting date x cultivar interaction was highly significant for cob length (Table 4.1). At optimum planting date, PAN6017 attained cob length value of 19.3 cm, which was significantly longer than for DKC63-20 and SAM49. However, at early planting date ENERGY and PAN6017 attained longest cobs of 18.2 and 17.8 cm compared to DKC63-20, Phb3203 and SAM49, respectively. PAN6017 was again superior to other cultivars at late planting date with longest cobs of 19.0 cm. PAN6017 and Phb3203, although optimum and late planting dates were similar, surpassed early planting date, which produced the shortest cobs of 17.8 cm and 17.1 cm. DKC63-20 and ENERGY did not show any significant differences between planting dates. For SAM49, optimum planting date produced longer cob length than early and late planting dates. Younas *et al*. (2002) reported that shorter cobs on the stalk are desirable because it is less susceptible to lodging as strong winds at or near maturity can cause severe lodging and substantial yield loss.

At Potchefstroom, planting date was highly significant for cob length (Table 3.3). In contrast to Bethlehem, plant established late at Potchefstroom was superior with cob length of 17.7 cm, followed by those of optimum planting date with 17.1 cm, whereas early planting date attained shortest cobs of 15.3 cm (Table 4.4). Shortest cobs at early planting date agrees with findings of Madonni *et al*. (1998) who reported that decreased incident solar radiation early in the season reduced both cob length and cob mass through reductions in biomass production.

Table 4.1 PR>F-values from the analysis of variance for cob number, cob length (cm), cob mass (kg ha^{-1}), kernel number per cob (KNC), hundred (100) seed mass (g) and grain yield (kg ha^{-1}) at Bethlehem

Treatment Effects	Cob number	Cob length (cm)	Cob mass (kg ha^{-1})	Kernel Number per cob	100 kernel mass (g)	Grain yield (kg ha^{-1})
Planting date	0.0001	0.0001	0.0001	0.0057	0.0001	0.0001
Plant density	0.1527	0.6316	0.0001	0.7885	0.6011	0.0001
Pd x Pds	0.2084	0.7710	0.6775	0.2050	0.7088	0.5369
Cvs	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002
Pd x Cvs	0.0647	0.0009	0.0480	0.0961	0.3247	0.2061
Pds x Cvs	0.2540	0.4645	0.2604	0.3175	0.9371	0.2152
Pd x Pds x Cvs	0.5559	0.4527	0.7349	0.1723	0.8344	0.561
CV (%)	14	6.1	16.3	7.1	5.4	16.2

Pd x Pds = planting date x plant density interaction

Cvs = cultivars

Pd x Cvs = planting date x cultivar interaction

Pds x Cvs = plant density x cultivar interaction

Pd x Pds x Cvs = planting date x plant density x cultivar interaction

Table 4.2. Effect of planting date on cob number, cob length (cm), cob mass (kg ha^{-1}), KNC, hundred kernel mass (g) and grain yield (kg ha^{-1}) of five cultivars at Bethlehem

	Cultivars					
Planting date	PAN6017	DKC63-20	Phb3203	SAM49	ENERGY	Mean
			Cob number			
Early	28.0b	27.0bc	22.6efg	25.2bcde	23.7cdef	25.3a
Optimum	27.3b	32.1a	23.0efg	23.6def	26.6bcd	26.5a
Late	25.8bcde	23.0efg	21.4fg	21.8fg	20.1g	22.4b
Mean	27.0a	27.4a	22.3b	23.5b	23.5b	
			Cob length (cm)			
Early	17.8def	15.8g	17.1f	15.9g	18.2cde	17.0b
Optimum	19.3ab	15.9g	18.8abc	17.4ef	18.4bcd	18.0a
Late	19.0a	15.0g	18.4bcd	15.8g	17.9cdef	17.4b
Mean	18.7a	15.6c	18.1b	16.4d	18.2b	
			Cob mass (kg ha^{-1})			
Early	11517.8a	9690.0b	9896.7b	9428.9bc	9855.6b	10077.8a
Optimum	9061.1bc	8944.4bc	8254.4cd	7264.4de	9116.7bc	8528.2b
Late	8273.3cd	5314.4f	7132.2de	6173.3ef	6417.8ef	6662.2c
Mean	9617.4a	7982.9c	8427.8b	7622.2d	8463.4b	
			Kernel number per cob (KNC)			
Early	490.4fg	599.8ab	557.1cde	456.4gh	575.6bcd	535.9b
Optimum	521.4ef	627.4a	606.4ab	464.8gh	592.3abc	562.5a
Late	541.6de	581.0bc	599.9ab	451.8h	582.7bc	551.4ab
Mean	517.8c	602.7a	587.8ab	457.7d	583.5b	
			100 kernel mass (g)			
Early	43.4a	34.4g	39.5cd	41.9a	41.8ab	40.2a
Optimum	39.5cd	30.8h	36.0fg	40.1bc	36.5ef	36.6b
Late	39.1cd	31.5h	35.5fg	38.0de	36.5ef	36.1b
Mean	40.7a	32.2d	37.0c	40.0a	38.3b	
			Grain yield (kg ha^{-1})			
Early	9473.3a	8525.6ab	8465.6ab	7900.0bcd	8294.4bc	8531.8a
Optimum	7353.3cde	7602.2bcde	6832.2ef	5910.0fg	7223.3de	6984.2b
Late	6702.2ef	4903.3g	5938.9fg	5084.4g	5352.2g	5596.2c
Mean	7842.9a	7010.4b	7078.9b	6298.1c	6956.6b	

Means within the column followed by different letters are significantly different at $P \leq 0.05$ and 0.01

4.3.1.3. Cob mass

Cob mass at Bethlehem was significantly affected by the planting date x cultivar interaction (Table 4.1 & 4.2). At optimum planting date, PAN6017, DKC63-20, ENERGY and Phb3203 attained higher cob mass of 9061.1, 8944.4, 9116.7 and 8254.4 kg ha^{-1}, while SAM49 produced the lowest cob mass of 7264.4 kg ha^{-1}. At early planting date, PAN6017 exhibited the highest cob mass of 11517.8 kg ha^{-1}. PAN6017 was once again superior at late planting date compared to DKC63-20, SAM49 and ENERGY. For PAN6017, cob mass at early planting date was 27.1 and 39.2% higher than for optimum and late planting dates. For DKC63-20, optimum and early planting dates were superior to late planting date by 68.3 and 82.3%, respectively. Early planting date for Phb3203 was superior to both optimum and late planting dates. Early planting date was again superior for SAM49 and it was 29.8 and 52.7% more than optimum and late planting dates. For ENERGY, late planting date produced the lowest cob mass, which was 29.6 and 34.9% lower than optimum and early planting dates. Cob mass decreased from early to optimum planting and from optimum to late planting date. The cob mass of PAN6017 declined with 21.3 and 8.7%, respectively, from the early planting to the optimum and from the optimum to the late planting date. The cob mass of Phb3203 declined with 16.6 and 13.3 % from the early planting to the optimum and from the optimum to the late planting date. DKC6320 and ENERGY had a cob mass decline of 40.6 and 29.6% from optimum to late planting and 7.7 and 7.5% from early to optimum planting date, respectively. The cob mass of SAM49 declined with 23.0 and 15.0% from early planting to the optimum and from the optimum to the late planting date. Similar results had been obtained by Green *et al*. (1985) who reported that a delay in planting date beyond a given optimum date resulted in a progressive reduction in the yield and yield components of the crop because an increasing proportion of the available solar radiation was not intercepted by the crop canopy.

At Potchefstroom**,** cob mass was significantly affected by the planting date x cultivar interaction (Table 4.3 & 4.4). At optimum planting date, PAN6017 was prolific**,** with cob mass of 10777.8 kg ha^{-1}, while DKC63-20, Phb3203 and ENERGY followed with similar cob mass of 9222.2, 9000.0 and 9000.0 kg ha^{-1}, respectively. SAM49 exhibited the lowest cob mass of 7222.2 kg ha^{-1}. The trend for all cultivars in the early planting date was similar to that of optimum planting date. PAN produced highest cob mass of 7222.2 kg ha^{-1}, while DKC63-20, Phb3203 and ENERGY followed with similar cob mass of 5333.3, 5222.2 and 5000.0 kg ha^{-1}, respectively. SAM49 produced the lowest cob mass of 3555.6 kg ha^{-1}at the early planting date. At late planting date PAN6017 produced the highest cob mass of 7333.3 kg ha^{-1}, while DKC63-20, Phb3203 and SAM49 produced lowest cob mass of 4444.4, 5111.1 and 4888.9 kg ha^{-1}, respectively. PAN6017, DKC63-20, Phb3203 and ENERGY obtained the greatest cob mass at optimum planting date, while early and late planting dates were similar. For SAM49 it was not the case because there was a significant difference between early and late planting dates. In general, the average cob mass of PAN6017, Phb3203, DKC63-20, SAM49 and ENERGY for early and late planting dates were exceptionally lower than that of optimum planting date by 32.5, 42.6, 47.0, 41.5 and 43.2%, respectively. Therefore, planting early or late decreased cob mass by the same margins. Maddonni *et al*. (1998) ascribed low cob mass at early and late planting dates to decreased incident solar radiation that reduced final kernel mass and subsequently cob mass through reduction in biomass production.

Table 4.3 PR>F-values from the analysis of variance for cob number, cob length (cm), cob mass (kg ha^{-1}), kernel number per cob (KNC), hundred (100) kernel mass (g) and grain yield (kg ha^{-1}) of five cultivars at Potchefstroom

Treatment Effects	Cob number	Cob length (cm)	Cob mass (kg ha^{-1})	Kernel number per cob	100 kernel mass (g)	Grain yield (kg ha^{-1})
Planting date	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Plant density	0.2384	0.0439	0.0001	0.0335	0.9382	0.0001
Pd x Pds	0.3289	0.3362	0.7173	0.3711	0.6755	0.7423
Cvs	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Pd x Cvs	0.1708	0.0693	0.0296	0.0029	0.0001	0.0349
Pds x Cvs	0.8615	0.5266	0.7515	0.7543	0.5906	0.3601
Pd x Pds x Cvs	0.9954	0.6230	0.9462	0.5698	0.3520	0.9669
CV (%)	16.7	7.7	14.3	11.1	5.6	15.2

Pd x Pds = planting date x plant density interaction
Cvs = cultivars
Pd x Cvs = planting date x cultivar interaction
Pds x Cvs = plant density x cultivar interaction
Pd x Pds x Cvs = planting date x plant density x cultivar interaction

Table 4.4 Effect of planting date on the cob number, cob length (cm), cob mass (kg ha^{-1}), kernel number per cob (KNC), hundred (100) kernel mass (g) and grain yield (kg ha^{-1}) of five cultivars at Potchefstroom

			Cultivars			
Planting date	PAN6017	DKC63-20	Phb3203	SAM49	ENERGY	Mean
			Cob number			
Early	34.0cd	29.2defgh	24.3hi	24.8hi	21.8i	26.8b
Optimum	39.2ab	40.3a	30.6cdef	29.9cdefg	34.4bc	34.9a
Late	31.0cde	26.4efghi	24.0i	25.1ghi	25.7fghi	26.4b
Mean	34.7a	32.0a	26.3b	26.6b	27.3b	
			Cob length (cm)			
Early	16.0cd	14.1e	16.8c	14.2e	15.2de	15.3c
Optimum	18.9ab	15.4d	18.4b	16.1cd	16.7c	17.1b
Late	19.7a	15.8cd	18.0b	16.8c	18.4b	17.7a
Mean	18.2a	15.1c	17.7a	15.7c	16.8b	
			Cob mass (kg ha^{-1})			
Early	7222.2c	5333.3d	5222.2d	3555.6e	5000.0d	5266.7b
Optimum	10777.8a	9222.2b	9000.0b	7222.2c	9000.0b	9044.4a
Late	7333.3c	4444.4de	5111.1d	4888.9d	5222.2d	5400.00b
Mean	8444.4a	6333.3b	6444.4b	5222.2c	6407.4b	
			Kernel number per cob (KNC)			
Early	396.3e	439.0de	462.7cd	339.2f	397.3e	406.9c
Optimum	534.0b	607.3a	631.4a	495.0bc	586.0a	570.8a
Late	605.4a	508.7bc	595.0a	478.7cd	532.6b	544.1b
Mean	511.9b	518.3b	563.0a	437.6c	505.3b	
			100 kernel mass (g)			
Early	44.8a	37.3ef	40.1d	40.4cd	42.9b	41.1a
Optimum	41.9bc	32.9g	36.8f	40.0d	38.9de	38.1b
Late	36.4f	34.4g	34.0g	37.1f	37.8ef	36.0c
Mean	41.0a	34.9d	37.0c	39.2b	39.9b	
			Grain yield (kg ha^{-1})			
Early	5777.8c	4555.6d	4000.0d	3000.0e	4222.2d	4311.1b
Optimum	9222.2a	8000.0b	7888.9b	6111.1c	8000.0b	7844.4a
Late	6000.0c	3777.8de	4111.1d	3888.9de	4333.3d	4422.2b
Mean	7000.0a	5444.4b	5333.3b	4333.3c	5518.5b	

Means within the column followed by different letters are significantly different at $P \leq 0.05$ and 0.01

4.3.1.4. Kernel number per cob (KNC)

Kernel number per cob (KNC) was significantly affected by planting date at Bethlehem (Table 4.1). Optimum and late planting dates produced the greatest KNC of 562.5 and 551.4, respectively, while early planting date obtained 535.9 (Table 4.2).

Contrary to Bethlehem, the cultivar x planting date interaction was highly significant for KNC at Potchefstroom (Table 4.3 & 4.4). At optimum planting date, DKC63-20, Phb3203 and ENERGY produced the highest KNC of 607.3, 631.4 and 586.0, respectively, while PAN6017 and SAM49 produced the lowest KNC of 534.0 and 495.0. Phb3203 exhibited the highest KNC of 462.7 at early planting date**,** while SAM49 produced the lowest KNC of 339.2. At late planting date, PAN6017 and Phb3203 produced highest**,** similar KNC of 605.4 and 595.0**,** followed by ENERGY, DKC 63-20 and SAM 49 with 532.6, 508.7 and 478.7, respectively. For PAN6017, late planting date was superior with 605.4, followed by optimum with 534.0**,** and early planting date produced the lowest KNC of 396.3. However, for DKC63-20 optimum planting date produced the highest KNC of 607.3, followed by late planting date with 508.7, while early planting obtained the lowest KNC of 439.0. Early planting date for Phb3203 was 26.7 and 22.2% lower than optimum and late planting dates. For SAM49, early planting date was 31.5 and 29.1 % less than optimum and late planting dates. Optimum planting date for ENERGY was the highest with 586.0, followed by late planting with 532.6, while early planting obtained the lowest KNC of 397.3. The increase in KNC at optimum planting date is in contrast with results of Harris *et al*. (1984) who found variation in planting date to have a negligible influence upon the number of kernels per ear.

4.3.1.5. Hundred (100) kernel mass

Planting date caused significant difference in hundred (100) kernel mass at Bethlehem (Table 4.1). Plants established early produced higher hundred (100) kernel mass of 40.2 g, whereas those of optimum and late planting dates attained lower 100 kernel mass of 36.6 and 36.1 g, respectively (Table 4.2). The low 100 kernel mass at late planting date confirms findings of Gallagher *et al*. (1975), who reported that delay in planting date generally result in decreased individual grain mass, cob number per plant and eventually decrease in grain yield.

At Potchefstroom, the cutivar x planting date interaction was highly significant for 100 kernel mass (Table 3.3). At optimum planting date, PAN6017 obtained higher 100 kernel mass of 41.9 g, while DKC63-20 produced the lowest kernel mass of 32.9 g. At early planting date, the trend was similar to optimum planting date and once again PAN6017 was superior with 100 kernel mass of 44.8 g, while DKC63-20 produced the lowest kernel mass of 37.3 g (Table 4.4). At late planting date, ENERGY, SAM49 and PAN6017, produced the highest kernel mass of 37.8, 37.1 and 36.4 g, respectively, while DKC63-20 and Phb3203 produced the lowest values of 34.4 and 34.0 g. For PAN6017, early planting date was higher with 44.8 g, followed by optimum planting with 41.9 g and late planting date produced the lowest value of 36.4 g. There were no significant differences between optimum and late planting dates for DKC63-20, but early planting date differed significantly. For Phb3203, early planting date out yielded both optimum and late planting dates. Late planting date for SAM49 was lower than optimum and early planting dates with margins of 8.2 and 7.3 %. For ENERGY, early planting date was 10.3 and 13.5% more than optimum and late planting dates. On average all cultivars had higher 100 kernel mass at early planting date, which declined at optimum planting date and declined even further at late planting date. These results confirmed those of Taylor & Blackett (1982) and were probably due to lower biomass production at anthesis for late planted crops since they have the tendency to give lighter kernels. Madonni *et al.* (1998) found that kernel mass is determined by post-silking crop growth, with more dependence on reserve mobilization in hybrids with small kernels and high kernel number relative to hybrids with fewer kernel number and large size.

4.3.1.6 Grain yield

At Bethlehem, planting date was highly significant for grain yield (Table 4.1). Maize at early planting date was superior with grain yield of 8531.8 kg ha^{-1}, which was 22.2 and 52.5% more than optimum and late planting dates, thereby confirming previous results of Otequi & Melon (1997), who reported high grain yield of earlier planted maize than late planted maize. In addition, Schoper *et al*. (1982) reported that increasing light interception through early planting date has increased maize yields. In a study carried out by Johnson and Mulvaney (1980) higher grain moisture and 5% yield loss was generally recorded at harvest in the case of later planted maize hybrids. Bauer and Carter (1986) not only found a correlation between the planting date and grain yield, but also noted that late planting date led to more brittle grains, causing storage problems. Chaudry (1994) also reported that planting outside optimum planting date might decrease grain yield.

At Potchefstroom, the cultivar x planting date interaction was significant for grain yield (Table 4.3 & 4.4). At optimum planting date, PAN6017 out yielded all the cultivars with higher grain yield of 9222.2 kg ha^{-1}. DKC63-20 and ENERGY, followed with the same value of 8000.0 kg ha^{-1}, while SAM49 produced lower grain yield of 6111.1 kg ha^{-1} (Table 4.4). At early planting date the trend amongst the cultivars was similar to that at optimum planting date. Once again PAN6017 was superior and produced higher grain yield of 5777.8 kg ha^{-1}. DKC63-20, ENERGY and Phb3203 followed with similar values of 4555.6, 4222.2 and 4000.0 kg ha^{-1}, respectively, while SAM49 obtained the lowest of 3000.0 kg ha^{-1}. PAN6017, at late planting obtained higher grain yield of 6000.0 kg ha^{-1}. Phb3203, ENERGY, DKC63-20 and SAM49 attained similar grain yields of 4111.1 kg ha^{-1}, 4333.3 kg ha^{-1}, 3777.7 kg ha^{-1} and 3888.9 kg ha^{-1}, respectively. All cultivars did not show significant differences between early and late planting dates, but optimum planting date showed differences. For PAN6017, optimum planting date was 59.6 and 53.7% higher than early and late planting dates**,** while optimum planting date for DKC63-20 was 75.6 and 91.1% more than early and late planting dates. For Phb3203, optimum planting date was 97.2 and 91.9% more than early and late planting dates. For ENERGY, optimum planting date was 89.5 and 84.6% more than early and late planting dates. However, for SAM49, there was no significant difference between early and late planting dates, but grain yield were 51.0 and 36.4% less than that at optimum planting date. All cultivars produced the highest grain yield at optimum planting date, whereas mixed and varying values were obtained at early and late planting dates.

Previous investigations on the effect of planting date on grain yield and yield components have found a positive correlation between cob mass, cob number per plant, kernel number per plant and grain yield (Ahmadi *et al*., 1993). Otequi *et al*. (1995) reported that optimum planting date resulted in higher grain yield than early and late planting dates because of higher cob numbers and greater kernel number per plant. In addition, Chaudry (1994) also reported that for economic yield, the seed must be planted at optimum planting date. According to Imholte and Carter (1987), for some hybrids early planting date leads to outstanding increase in yield and to lower grain moisture content at harvest, thus improving production efficiency.

In general early planting date performed best at Bethlehem and optimum planting date was best for Potchefstroom. This could be attributed to the fact that there were enough rainfall and temperatures during those periods at both localities.

4.3.2. Effect of plant densities

4.3.2.1. Cob mass

At Bethlehem, plant density was significant for cob mass (Table 4.1 & 4.5). The optimum plant density produced higher cob mass of 8434.4 kg ha^{-1}, followed by low plant density with 7259.1 kg ha^{-1}, while high plant density obtained lower value of 5576.3 kg ha^{-1}. The results confirms previous investigations by Tetio-Khago & Gardner (1988) who have shown that high plant density reduces light interception per plant, and that it is likely that mutual shading negatively affect source capacity to supply the ear with photoassimilate, which subsequently decreases the cob mass.

Similar to Bethlehem, plant density was significant for cob mass at Potchefstroom (Table 4.3 & 4.6). The trend for cob mass was similar to that at Bethlehem, with optimum plant density out yielding low and high plant densities with 23.0 and 70.6%, respectively. Previous investigations on the effect of plant density on cob mass have shown that high plant density decreased the mass and diameter of cobs (Hatfield *et al*., 1984; Hashemi-Dezfouli, 1992). Dungan *et al*. (1958) found that maize cob mass per plant decreased linearly as plant density increased.

4.3.2.2. Cob length

At Bethlehem, plant density was non-significant for cob length (Table 4.1 & 4.6). In contrast to Bethlehem, cob length was significantly affected by the plant density at Potchefstroom (Table 4.3 & 4.6). Maize at optimum plant density produced the longest cobs of 14.0 cm, while those at low and high plant densities produced similar cob lengths of 13.5 and 13.6 cm, respectively. Begna (1996) found decreased cob diameter and cob length as plant density increased, and conventional hybrids were affected more than leafy, reduced stature hybrids.

4.3.2.3. Cob numbers

At both Bethlehem and Potchefstroom, cultivars differed significantly in terms of cob numbers, whereas plant density was non-significant (Table 4.1 & 4.5).

4.3.2.4. Kernel number per cob (KNC)

At both Bethlehem and Potchefstroom, plant density was non-significant for KNC (Table 4.1 & 4.3).

4.3.2.5. Hundred (100) kernel mass

At both Bethlehem and Potchefstroom, plant density was non-significant for 100 kernel mass (Table 4.1 & 4.6).

Table 4.5 Effect of plant density on the cob number, cob length (cm), cob mass (kg ha^{-1}), kernel number per cob (KNC), hundred (100) kernel mass (g) and grain yield (kg ha^{-1}) of five cultivars at Bethlehem

			Cultivars			
Plant density	PAN6017	DKC6320	Phb3203	SAM49	ENERGY	Mean
			Cob number			
Low	26.6a	26.7a	22.2cd	20.7d	22.6cd	23.8a
Optimum	22.7cd	26.3ab	19.9d	22.1cd	20.8d	22.4a
High	26.8a	24.3abc	20.1d	23.0bcd	22.4cd	23.3a
Mean	25.5a	25.8a	20.7b	21.9b	21.9b	
			Cob length (cm)			
Low	17.4a	14.2def	15.8c	14.8d	16.1bc	15.7a
Optimum	16.7abc	13.4f	16.6abc	14.6de	16.7abc	15.6a
High	17.0ab	13.7ef	16.2bc	14.1def	16.2bc	15.4a
Mean	17.0a	13.8d	16.2b	14.5c	16.3b	
			Cob mass (kg ha^{-1})			
Low	8841.1a	6661.1de	7836.0abcd	5922.2ef	7035.3cde	7259.1b
Optimum	8893.3a	8047.4abc	8338.4ab	7920.6abcd	8972.1a	8434.4a
High	7131.1bcde	5256.6f	5112.2f	5003.1f	5378.3f	5576.3c
Mean	8288.5a	6655.0c	7095.5b	6282.0d	7128.6b	
			Kernel number per cob (KNC)			
Low	441.9c	537.8ab	517.4b	389.3d	513.8b	480.0a
Optimum	444.7c	511.1b	523.0ab	391.8d	527.9ab	479.7a
High	450.9c	551.4a	515.1b	382.0d	506.9b	481.3a
Mean	445.8b	533.4a	518.5a	387.7c	516.2a	
			100 kernel mass (g)			
Low	37.8a	29.6e	34.7cd	37.9a	35.3bc	35.1a
Optimum	37.7a	29.3e	33.6d	37.1ab	35.6bc	34.7a
High	38.2a	29.4e	34.4cd	36.8ab	35.3bcd	34.8a
Mean	37.9a	29.4c	34.3b	37.3a	35.4b	
			Grain yield (kg ha^{-1})			
Low	7382.1ab	6444.6bc	6819.9abc	5159.1de	6117.6cd	6384.7b
Optimum	7548.8a	7259.9ab	7268.3ab	6803.3abc	7757.6a	7327.6a
High	6101.0cd	4769.7e	4597.6e	4388.1e	4438.9e	4859.1c
Mean	7010.6a	6158.1b	6228.6b	5450.2c	6104.7b	

Means within the column followed by different letters are significantly different at $P \leq 0.05$ and 0.01

4.3.2.6. Grain yield

At Bethlehem, plant density caused significant differences in grain yield (Table 4.1 & 4.5). Maize at optimum plant density was superior with grain yield of 7327.6 kg ha^{-1}, followed by those at low plant density with 6384.7, while high plant density obtained the lowest grain yield of 4859.1 kg ha^{-1}. These results confirm those of Tollenaar *et al.* (1997) that maize grain yield declines when plant density is increased beyond the optimum plant density, primarily because of intense interplant competition for incident photosynthetic photon flux density, nutrients and water. Density-yield studies are very useful for evaluating the reaction of plants to their neighbours (Jolliffe, 1988). Under weed-free conditions, maize yield increases with an increase in plant density, until an optimum plant density is reached (Tollenaar, 1991). Daynard & Muldoon (1983) and Buren *et al.* (1994) reported that the number of plants at low or high plant density becomes a limiting factor for the yield of maize crops. At low plant density the number of plants limit yield because of few cobs produced, whereas at high plant density yield is limited by the number of barren plants and a decrease in number of kernels per ear or both (Hashemi-Dezfouli & Herbert, 1992).

At Potchefstroom, grain yield was significantly affected by plant density (Table 4.3 & 4.6). Maize at low and high plant densities yielded 18.3 and 38.1% lower than at optimum plant density. These results support observations of Vega *et al.* (2001) that increasing plant density beyond the optimum will decrease grain yield per plant, mainly due to the effects of interplant competition for light, water, nutrients and other environmental factors. In addition, Duncan (1984) mentioned that it is a well known fact that the grain yield of a single maize plant is reduced by the nearest of its neighbours. Reductions in grain yield at high plant density may have resulted from fewer flowers being formed prior to flowering, poor pollination resulting from asynchrony of tasselling and silking, or from abortion of kernels after fertilization (Daynard & Muldoon 1983; Karlen & Camp 1985; Hashemi-Dezfouli & Herbert, 1992). The authors also reported that maize grain yield is more affected by variations in plant density as compared to other cereal crops

Table 4.6 Effect of plant density on the cob number, cob length (cm), cob mass (kg ha^{-1}), kernel number per cob (KNC), hundred (100) kernel mass (g) and grain yield (kg ha^{-1}) of five cultivars at Potchefstroom

			Cultivars			
Plant density	PAN6017	DKC63-20	Phb 3203	SAM49	ENERGY	Mean
Cob number						
Low	23.7ab	24.2ab	16.4de	16.9cde	16.2de	19.5a
Optimum	23.9ab	19.4bcd	15.9de	14.1e	17.1cde	18.1a
High	26.2a	21.8abc	16.6de	17.8cde	17.4cde	19.9a
Mean	24.6a	21.8b	16.3c	16.3c	16.9c	
Cob length (cm)						
Low	15.2ab	12.3g	13.9cde	12.6fg	13.6def	13.5b
Optimum	15.5ab	12.0g	15.9a	12.9efg	13.9cde	14.0a
High	14.8abc	12.1g	14.4bcd	12.7fg	13.8cde	13.6b
Mean	15.2a	12.1d	14.7b	12.7d	13.8c	
Cob mass (kg ha^{-1})						
Low	7418.4ab	5579.5de	5239.7e	4016.9fg	5018.9ef	5454.7b
Optimum	8465.4a	6128.0cde	6575.5bcd	5238.1e	7129.5bc	6707.3a
High	5794.7de	3684.6gh	3908.8fgh	2799.7h	3466.4gh	3930.8c
Mean	7226.2a	5130.7b	5241.3b	4018.2c	5204.9b	
Kernel number per cob (KNC)						
Low	362.7bc	397.2ab	403.4ab	295.6ef	353.3bcd	362.4a
Optimum	367.0bc	365.1bc	439.7a	307.1def	378.2bc	371.4a
High	359.7bc	344.1cde	398.8ab	269.2f	338.6cde	342.1a
Mean	363.1b	368.8b	414.0a	290.6d	356.7c	
100 kernel mass (g)						
Low	32.5a	26.9de	28.3cd	29.9bc	31.6ab	29.8a
Optimum	32.4a	25.7e	28.2d	31.4ab	30.9ab	29.7a
High	33.2a	26.4e	28.7cd	30.5b	31.5ab	30.1a
Mean	32.7a	26.3d	28.4c	30.6a	31.3a	
Grain yield (kg ha^{-1})						
Low	6817.8ab	5151.3cd	4818.9d	3817.9ef	4593.9de	5040.0b
Optimum	7489.6a	5819.9c	6042.2bc	4706.6de	6814.9ab	6174.6a
High	5155.3cd	3818.5ef	3599.7f	2939.0f	3595.8f	3821.7c
Mean	6487.6a	4929.9b	4820.3b	3821.2c	5001.5b	

Means within the column followed by different letters are significantly different at $P \leq 0.05$ and 0.01

4.3.3. Cultivar effect

4.3.3.1. Cob numbers

At Bethlehem, cultivars showed significant differences in cob number (Table 4.1 & 4.2). PAN6017 and DKC63-20 produced higher cob number of 27.0 and 27.4, while Phb3203, SAM49 and ENERGY attained lower cob number of 22.3 and 23.5, respectively. Cob number was also significantly affected by cultivar effect at Potchefstroom (Table 4.3 & 4.4). PAN6017 and DKC63-20 attained higher number of cobs, while Phb3203, SAM49 and ENERGY, obtained lower number of cobs.

4.3.3.2. Cob length

Cultivar effect showed a highly significant difference for cob length at both localities. At Potchefstroom, PAN6017 and Phb3203 produced the longest cobs of 18.2 and 17.7 cm, followed by ENERGY with 16.8 cm, while DKC63-20 and SAM49 attained the shortest cobs of 15.1 and 15.7 cm, respectively (Table 4.3 & 4.4). At Bethlehem, PAN6017 produced the longest cob length of 18.7 cm, while SAM49 attained the shortest cob length of 15.6 cm (Table 4.1 & 4.2).

4.3.3.3. Kernel number per cob (KNC)

At Bethlehem, cultivars differed significantly in terms of KNC (Table 4.1 & 4.2). DKC63-20 and Phb3203 produced higher KNC of 602.7 and 587.8. ENERGY followed with 583.5, PAN6017 with 517.8 and SAM49 the lowest KNC of 457.7. Derieux *et al.* (1985) observed a significant relationship between kernel set per row and final ovule number per row for certain genotypes planted on different dates. KNC was also significantly affected by cultivar effect at Potchefstroom (Table 4.3 & 4.4). Phb3203 produced higher KNC of 414, while SAM49 was the lowest with 290.6.

4.3.3.4. Hundred (100) kernel mass

At both localities, cultivar differed significantly in terms of hundred (100) kernel mass (Table 4.1 & 4.3). At Bethlehem, PAN6017 and SAM49 produced higher kernel mass of 40.7 and 40.0 g, respectively. ENERGY followed with 38.3 g, Phb3203 with 37.0 g and DKC63-20 was the lowest with 32.2 g (Table 4.2). At Potchefstroom, PAN6017, ENERGY and SAM49 produced higher hundred kernel mass of 32.7, 31.1 and 30.6, respectively. Phb3203 followed with 28.4 and DKC63-20 was the lowest with 26.3 (Table 4.4).

4.3.3.5. Grain yield

At Bethlehem, cultivar caused significant difference in grain yield (Table 4.1 & 4.2). PAN6017 was most prolific with mean grain yield of 7843.0 kg ha^{-1}, followed by DKC63-20, Phb3203 and ENERGY with similar values of 7010.4, 7078.9 and 6956.6 kg ha^{-1}, respectively, while SAM49 attained lower grain yield of 6298.1 kg ha^{-1} (Table 4.2). The results of planting date experiments carried out by Bochicchio (1985) indicated that maize hybrids with short vegetation periods are less sensitive to late planting date than their long vegetation periods hybrids. Similar to Bethlehem, cultivar showed significant difference for grain yield at Potchefstroom (Table 4.3 & 4.4). The trend was the same with PAN6017 producing highest grain yield of 6487.6 kg ha^{-1}, while SAM49 was the lowest with grain yield of 3821.2 kg ha^{-1}.

4.3.3.6 Conclusions

At both localities, under optimum and early planting dates, the cultivar PAN6017 produced the highest yield components and grain yield, while SAM49 attained the lowest. PAN6017 also produced the highest yield components and grain yield at low and optimum plant densities**,** while SAM49 produced the lowest. However, in order to generalize these findings, more research over a wider range of locations and seasons should be conducted. Moreover, optimum planting date performed best at Bethlehem, while early planting date was the best at Potchefstroom. This could be attributed to higher rainfall during those periods at both localities. As for plant density, optimum plant density performed better than low and high density at both localities.

References

AHMADI, M., WIEBOLD, W.J., BEUERLEIN, J.E., ECKERT, D.J. & SCHOPER, J., 1993. Agronomic practices that affect corn kernel characteristics. *Agron. J.* 85, 615-619.

ALDRICH, S.R., SCOTT, W.O. & HOEFT, R.G., 1986. Modern corn production. A and Publ., Champaign, IL.

BAUER, P & CARTER, P.R., 1986. Effect of planting date, plant density moisture availability and soil nitrogen fertility on maize kernel breakage susceptibility. *Crop Sci*. 26, 1220-1226.

BEGNA, S.H., 1996. Effect of population density on the vegetative growth of leafy reduced-stature maize in a short-season area. *J. Agron*. *Crop Sci*. 12, 70-83

BERGMANN, M.K & TURPIN, F.T., 1984. Effect of sowing date on the dynamics of populations of Diabrotica spp in maize. Envir. Ent, College Park, 13, 888-901.

Bochicchio, A., 1985. Zea mays L. and chilling conditions at sowing time. Review. *Maydica*, 241-256.

BOLLERO, G.A., BULLOCK, D.G. & HOLLINGER, S.E., 1996. Soil temperature and planting date effect on corn yields, leaf area and plant development. *Agron*. *J*. 88, 385-390.

BROOKING, I.R. & KIRBY, EJ.M., 1981. Interrelationships between stem and ear development in winter wheat: Effect of a Norin 10 dwarfin gene/rht2. *J. Agric*. *Sci*. 97, 373-380.

BUREN, L.L., MOCK, J.J. & ANDERSON, I.C., 1994. Morphological and physiological traits in maize associated with tolerance to high plant density. *Crop Sci*. 14, 426-429.

CHAUDRY, A.R., 1994. Cereal crop in crop productivity. *J. Plant Sci*. 3, 262-265

CIRILO, A.G & ANDRADE, F.H., 1994. Sowing date and maize productivity: I. Crop growth and dry matter partitioning. *Crop Sci*. 34, 1039-1043.

COX, W.J., 1996. Forage quality and harvest index of corn hybrids under different growing conditions. *Agron*. *J*. 86, 277-282.

DAYNARD, T.B & MULDOON, J.F., 1983. Plant to plant variability of maize plants grown at different densities. *Can*. *J*. *Plant Sci*. 63, 45-59.

DERIEUX, M., BONHOMME, R., DUBURCQ, J.B. & RUGET, F., 1985. Variations du nombre de grains chez differents genotypes de mais. *Agron*. *J*. 5, 355-359.

DUNCAN, W.G., 1984. A theory to explain the relationship between corn population and grain yield. *Crop Sci*. 24, 1141-1145.

DUNGAN, G.H., LENG, A.L & PENDELTON, J.W., 1958. Corn plant population in relation to soil productivity. *Adv. Agron.* 10, 435-473.

DWYER, L.M., MA, B.L, EVENSON, L & HAMILTON, R.I., 1994. Maize physiological traits related to grain yield and harvest moisture in mid-to-short season environments. *Crop Sci.* 34, 985-992.

GALLAGHER, E.G., KASPERBAUER, M.J. & HUNT, P.G., 1975. Planting patterns and radiation interception, plant nutrient concentration and yield in corn. *Agron. J.* 81, 167-174.

GREEN, T.S., ENDER, M. & MOCK, J.J., 1985. Effect of sowing dates on maize yields. *Agric. Sci.* 20, 51-63.

HARRIS, R.E., MOLL, R.H. & STUBER, C.W., 1984. Control and inheritance of prolificacy in maize. *Crop Sci.* 16, 843-850.

HASHEMI, A.M., HERBERT, S.J. & PUTNAM, D.H., 2005. Yield response of corn to crowding stress. *Agron. J.* 97, 839-846.

HASHEMI-DEZFOULI, A & Herbert, S.J., 1992. Intensifying plant density response of corn with artificial shade. *Agron. J.* 84, 547-551.

HATFIELD, A.L., BENOIT, G.R & RAGLAND, J.L., 1984. The growth and yield of corn. IV. Environmental effects on grain yield components of mature ears. *Agron. J.* 57, 293-295.

IMHOLTE, A.A & CARTER, P.R., 1987. Planting date and tillage effects on corn following corn. *Agron. J.* 42, 746-751

JOLLIFFE, P.A., 1988. Evaluating the effects of competitive interference on plant perfomance. *J. Theor. Biol.* 130, 447-4457.

JOHNSON, R.R & MULVANEY, D.L., 1980. Development of a model for use maize replant decisions. *Agron. J.* 50, 459-464.

JOUNAS, M., RAHMAN, H & HAYDER, G., 2002. Magnetitute of variability for yield and yield asociated traits in maize hybrids. *J. Plan Sci.* 6, 694-696.

KARLEN, D.L & CAMP, P.E., 1985. Row spacing, plant population and water management effects on corn in the Atlantic Coastal Plain. *Agron. J.* 77, 771-715.

KHAN, N., QASIM, M, AHMED, F & KHANZADA, S.A., 2002. Effect of sowing dates on yield of maize under agroclimatic conditions. *J. Plant Sci.* 2, 146-149.

MADDONNI, G.A., OTEGUI, M.E. & BONHOMME, R., 1998. Grain yield components in maize: II. Postsilking growth and kernel weight. *Field Crops Res*. 56, 257-264.

McCULLOUGH, D.E., GIRARDIN, P, AQUILERA, A & TOLLENAAR, M., 2000. Influence of N supply on development of and dry matter accumulation on an old and a new maize hybrid. *Can. J. Plant Sci*. 74, 471-477.

NAFZIGER, E.D., CARTER, P.R. & GRAHAM, E.E., 1994. Response of corn to uneven emergence. *Crop Sci*. 31, 811-815.

OTEGUI, M., 1995. Prolificacy and grain yield components in modern Argentinian maize hybrids. *Maydica*. 40, 371-376.

OTEGUI, M.E. & MELON, S., 1997. Kernel set and flower synchrony within the ear of maize: I. Sowing date effects. *Crop Sci*. 37, 441-447.

OTEGUI, M.E., NICOLINI, M.G., RUIZ, R.A. & DODDS, P.A., 1995. Sowing date effects on grain yield components for different maize genotypes. *Agron. J*. 87, 29-33.

PRINCE, G.M & SCHORDER, V.N., 1964. Above-soil environment limits yields of semiprolific corn as plant population increases. *Crop Sci*. 4, 361-362.

RACZ, I., KOVACS, M, VEIZ, D & PALDI, G., 1996. Effect of short term and long term low temperature stress on polyamine biosynthesis in wheat genotypes with varying degrees of frost tolerance. *J. Plant Physiol*. 3, 368-373

SCHOPER, J.B., JOHNSON, R.R & LAMBERT, R.J., 1982. Maize yield response to increased assimilate supply. *Crop Sci*. 22, 1184-1189.

SCHUSSLER, J.R. & WESTGATE, M.E., 1995. Assimilate flux determines kernel set at low water potential in maize. *Crop Sci*. 35, 1074-1080.

STINSON, H.T. & MOSS, D.N., 1986. Some effects of shade upon corn hybrids tolerant and intolerant of dense plantings. *Agron. J*. 52:482-484.

TAYLOR, H.M. & BLACKETT, P.S., 1982. Soybean and maize yield as affected by row spacing, planting dates and seasonal water supply. *Agron. J*. 80, 930-935.

TOLLENAAR, M., 1978. Sink-source relationship during reproductive development in maize. *Maydica*. 22, 49-75.

TOLLENAAR, M., 1991. Physiological basis of genetic improvement of maize hybrids in Ontario from 1959 to 1988. *Crop Sci*. 31, 119-124.

TOLLENAAR, A., AGUILERA, A & NISSANK, S.P., 1997. Grain yield is reduced more by weed interference in an old than in a new maize hybrid. *Agron. J.* 89, 239-246.

THORNE, G.N., 1982. Distribution between parts of the main shoot and the tillers of photosynthate produced before and after anthesis in the top three leaves of main shoots of winter wheat. *Annu. Appl. Biol.* 101, 553-559.

TETIO-KAGHO, F & GARDNER, F.P., 1988. Response of maize to plant population density. I. Canopy development, light relationships and vegetative growth. *Agron. J.* 80, 930-935.

VEGA, C.R.C., ANDRADE, F.H., SADRAS, V.O., UHART, S. & VALENTINUZ, O.R., 2001. Seed number as a function of growth. A comparative study in soybean, sunflower and maize. *Crop Sci.* 41, 748-754.

CHAPTER 5: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1. Discussion

LAI and distribution of leaf area within a maize canopy are major factors determining total light interception, which affects photosynthesis, transpiration and dry matter production (Stewart & Dwyer, 1999). At Potchefstroom, planting date and cultivar significantly affected leaf area index (LAI) and dry matter production. Maize at late planting date produced higher LAI and dry matter yield compared to optimum and early planting dates. In contrast to Potchefstroom, early planting date at Bethlehem produced higher LAI and dry matter yield than at optimum and late planting dates. The differences in LAI and dry matter yield at Potchefstroom and Bethlehem could be attributed to differences in heat units (average temperatures) and rainfall distribution between two localities. High rainfall distribution late in the season at Potchefstroom contributed significantly to high LAI and dry matter yield for late planting date, while the same holds true for early planting date at Bethlehem. Cultivars PAN6017 and Phb3203 produced the highest LAI and dry matter yield at both localities while SAM49 produced the lowest. For the plant density effect, the trend for LAI and dry matter was the same for both localities. As expected, optimum plant density produced the highest LAI and dry matter, followed by low plant density, and high plant density produced the lowest. PAN6017 and Phb3203 once again produced the highest LAI and dry matter yield of all cultivars.

Tollenaar & Aquilera (1992) found that late planting dates reduced cumulative intercepted PAR from flowering to physiological maturity, mainly because of their low values of daily incident radiation. Planting date and cultivar effects significantly affected days to 50% flowering and physiological maturity. Early planting date reached days to 50% flowering and physiological maturity earlier than optimum and late planting dates at both localities. However, the main difference between the two localities is that at Potchefstroom early planting date reached 50% flowering and physiological maturity much earlier than at Bethlehem. Late planting date plants at Potchefstroom flowered at the same time as those at the optimum planting date at Bethlehem. DKC63-20 and

ENERGY reached days to 50% flowering and physiological maturity earlier than PAN6017, SAM49 and Phb3203. This could be attributed to the fact that the former are ultra-short cultivars and the latter are short cultivars. In general, factors underlying these differences could also be speculated to be differences in heat units between Potchefstroom and Bethlehem, since the former seems to accumulate more heat units than the latter. Heat units play an important role in cooler production regions like Bethlehem. The shorter the days get, the less heat units are available per day, and the longer it takes for plants to flower and mature.

The planting date x cultivar interaction significantly affected grain yield at Potchefstroom. Plants at optimum and early planting dates performed the same, and in those cases, PAN6017 produced a higher grain yield, while SAM49 produced the lowest. These results agree with findings by Otequi *et al*. (1995) that optimum planting date resulted in higher grain yield than early and late planting dates because of higher cob numbers and greater kernel numbers per plant. At Bethlehem, early planting date produced a higher grain yield, followed by optimum planting date, while late planting date produced the lowest. These results contradicted findings of Chaudry (1994) that planting outside optimum planting date might decrease grain yield. As for the cultivars, PAN6017 produced a higher grain yield, while SAM49 produced the lowest. At both localities, grain yield was significantly affected by plant density and cultivars. Cultivar PAN6017 produced a higher grain yield, while SAM49 produced the lowest at both plant densities and localities. In general, optimum plant density produced higher grain yield than other plant densities at both localities.

Before any recommendations can be made, more research is needed to understand cutivars, cultural practices and environmental interactions.

5.2. Conclusions

Based on the work reported in this thesis the following conclusions can be made**:**

1. At all planting dates and plant densities**,** short growing season cultivars produced more leaves than ultra-short growth season cultivars**,** and as a result had a greater leaf area index and better light interception ability than the ultra-short cultivars. This resulted in higher dry matter accumulation for short season cultivars than ultra-short season cultivars.

2. Ultra-short season cultivars reached days to 50% flowering and physiological maturity earlier than short season cultivars. This could be due to the fact that ultra-short season cultivars required fewer heat units for tasselling and silking and had longer periods available for grain filling than short season cultivars.

3. In general, grain yield of short and ultra-short season cultivars were higher at early and optimum planting dates as well as at low and optimum plant densities, at both locations. In contrast to literature findings that short growing season cultivars are more tolerant of high plant density, our findings indicated that at both locations higher plant density produced lower grain yields than at both the low and optimum plant densities. Generally, cultivar PAN6017 produced a higher grain yield, while SAM49 produced the lowest (Table 5.1 & 5.2).

5.3. Recommendations

Based on the results reported in Table 5.1 and 5.2, the following recommendations can be made:

1. In order to broaden our understanding of short and ultra-short growth period maize cultivars, studies involving a larger number of these cultivars should be conducted over a wider range of locations and seasons.

2. In general, PAN6017 produced a higher grain yield at both localities, while SAM49 produced the lowest. However, to generalize these findings, more research over a wider range of locations and seasons should be conducted.

Table 5.1 Effect of plant densities and planting dates on grain yield at Bethlehem

			Low density			
	Planting date					
Cultivars	Early	Rank	Optimum	Rank	Late	Rank
PAN6017	7427.7	1	6367.7	1	6042.2	1
DKC 63-20	6485.1	3	6023.4	2	4674.0	4
Phb3203	6642.8	2	5826.1	3	5379.4	2
SAM49	5529.6	5	4534.6	5	4121.8	5
ENERGY	6206.0	4	5670.5	4	4734.9	3
			Optimum density			
	Planting date					
Cultivars	Early	Rank	Optimum	Rank	Late	Rank
PAN6017	7511.1	1	6491.1	1	6125.5	1
DKC 63-20	6892.8	3	6431.1	3	5081.6	4
Phb3203	6867.0	4	6050.3	4	5603.6	2
SAM49	6351.7	5	5356.7	5	4943.9	5
ENERGY	7026.0	2	6473.5	2	5554.9	3
			High density			
	Planting date					
Cultivars	Early	Rank	Optimum	Rank	Late	Rank
PAN6017	6787.2	1	5727.2	1	5401.6	1
DKC 63-20	5647.7	2	5186.0	2	3836.5	4
Phb3203	5531.6	3	4714.9	4	4268.3	2
SAM49	5144.1	5	4149.1	5	3736.3	5
ENERGY	5366.7	4	4831.1	3	3895.6	3

Table 5.2 Effect of planting density and planting date on grain yield at Potchefstroom

Low density

	Planting date					
Cultivars	Early	Rank	Optimum	Rank	Late	Rank
PAN6017	6297.8	1	7020.0	1	5408.9	1
DKC 63-20	4853.5	2	5575.7	2	3664.6	2
Phb3203	4409.5	3	5353.9	3	3565.0	3
SAM49	3409.0	5	3964.5	5	3053.4	5
ENERGY	4408.1	4	5297.0	4	3463.6	4

Optimum density

	Planting date					
Cultivars	Early	Rank	Optimum	Rank	Late	Rank
PAN6017	6633.7	1	7355.9	1	5744.8	1
DKC 63-20	5187.8	3	5910.0	4	3798.9	4
Phb3203	5021.1	4	5965.6	3	4076.7	3
SAM49	3853.3	5	4408.9	5	3497.8	5
ENERGY	5518.6	2	6407.5	2	4574.1	2

High density

	Planting date					
Cultivars	Early	Rank	Optimum	Rank	Late	Rank
PAN6017	5466.6	1	6188.7	1	4577.7	1
DKC 63-20	4187.1	2	4909.3	2	3698.2	2
Phb3203	3799.9	4	4744.3	4	3155.4	4
SAM49	3159.5	5	3525.1	5	3014.0	5
ENERGY	3909.0	3	4797.9	3	3264.6	3

References

CHAUDRY, A.R., 1994. Cereal crop in crop productivity. *J. Plant Sci.* 3, 262-265

OTEGUI, M.E., NICOLINI, M.G., RUIZ, R.A. & DODDS, P.A., 1995. Sowing date effects on grain yield components for different maize genotypes. *Agron. J.* 87, 29-33.

TOLLENAAR, M. & AGUILERA, A., 1992. Radiation use efficiency of an old and new maize hybrids. *Agron. J.* 84, 536-541.

STEWART, D.D. & DWYER, L.M., 1999. Mathematical characterization of leaf shape and leaf area of maize hybrids. *Crop Sci.* 39, 422-427.

CHAPTER 6: SUMMARY

Maize production accounts for 40% of the entire area cultivated in South Africa, and maize is conservatively estimated to be a staple food for more than 70% of the population (Du Toit, 2003). South African maize farmers annually plant approximately 3.7 million hectares, and of this area 3.5 million hectares are cultivated under dryland conditions, with an expected mean yield of 2.5 ton ha^{-1} (Agric Stat, 2004). In general, maize production is highly sensitive to climate variability and agronomic practices such as planting date, plant density and cultivar selection. A mixture of dry spells and erratic rainfall, with annual variation that cannot be predicted accurately and consistently, has a negative impact on growth and yield of maize (Benhil, 2002). This prompted research on specific factors that affect maize growth, yield and yield components.

In two field trials, one at Bethlehem and the other at Potchefstroom, the effects of planting date, plant density and cultivars were determined by measuring leaf area index (LAI), dry matter accumulation, days to 50% flowering, days to physiological maturity, plant height, cob numbers, cob mass, hundred (100) kernel mass, kernel number per cob and grain yield. At Potchefstroom, planting date and cultivar effects significantly affected LAI and dry matter yield. Plants at late planting date produced higher LAI and dry matter yield than those at optimum and early planting dates. In contrast to Potchefstroom, early planting date at Bethlehem produced higher LAI and dry matter yield than optimum and late planting dates. Cultivars PAN6017 and Phb3203 produced higher LAI and dry matter yield at both localities, and SAM49 the lowest. For the plant density effect, the trend for LAI and dry matter was the same for both localities. As expected, plants at optimum plant density produced higher LAI and dry matter yield, followed by low plant density, whilst high plant density produced the lowest. PAN6017 and Phb3203 once again produced higher LAI and dry matter yield than the other cultivars.

Planting date and cultivar effects significantly affected days to 50% flowering and physiological maturity. At both localities, early planting date caused plants to reach 50% flowering and physiological maturity earlier than those at optimum and late planting dates. However, the difference between the two localities was that at Potchefstroom early planting date reached 50% flowering and physiological maturity much earlier than at Bethlehem. Plants of the late planting date at Potchefstroom flowered at the same time as those of optimum planting date at Bethlehem. At both localities, DKC63-20 and ENERGY reached days to 50% flowering and physiological maturity earlier than PAN6017, SAM49 and Phb3203.

Planting date and cultivar effects were significant for plant height at both localities. At Potchefstroom, plants at optimum planting date produced the tallest plants compared to those at early and late planting dates. However, at Bethlehem, early planting date produced the tallest plants compared to late and optimum planting dates. As for cultivars, the trend was similar at both localities, with PAN6017 and ENERGY out-yielding other cultivars. Plant density effect produced similar results for both localities. Optimum and low plant densities produced the tallest plants compared to high plant density. This was mainly due to intense interplant competition for light, water and other growth resources at high plant density compared to optimum and low plant densities. The trend between cultivars was the same between the two localities. PAN6017 and ENERGY produced the tallest plants, while SAM49 and Phb3203 produced the shortest plants.

At Potchefstroom, plants at optimum planting date produced highest cob numbers, which were 30.2 and 32.2% more than those at the early and late planting dates. The same trend was observed at Bethlehem, and once again optimum planting date out-performed early and late planting dates. At both localities, PAN6017 and ENERGY produced higher cob numbers than SAM49, DKC63-20 and Phb3203. Plant density effect was the same for the two localities. Optimum plant density gave higher cob numbers than low and high plant densities.

At Potchefstroom, plants at late planting date produced the longest cobs, while early planting date produced the shortest. PAN6017 and Phb3203 produced the longest cobs, while SAM49 and DKC63-20 produced the shortest. Plant density effect was also significant at Potchefstroom. Plants at optimum plant density produced the longest cobs compared to those at early and late planting dates. As for the cultivars, PAN6017 was superior, while SAM49 produced the shortest cobs. In contrast to Potchefstroom, the planting date x cultivar interaction significantly affected the cob length at Bethlehem. In general, at all planting dates, PAN6017 and Phb3203 produced the longest cobs, while SAM49 produced the shortest. Cultivar significantly affected cob length, while the plant density effect was non-significant. PAN6017 produced the longest cobs at all plant densities, while DKC63-20 produced the shortest.

Reduced kernels per ear are the most consistent, irreversible component of yield reduction in maize (Anderson *et al*., 2004). At Potchefstroom, kernel number per cob (KNC) was significantly affected by the planting date x cultivar interaction. DKC63-20, Phb3203 and ENERGY produced the highest KNC at optimum planting date, while SAM49 and PAN6017 produced the lowest. However, at late planting date the trend changed because PAN6017 and Phb3203 produced higher KNC than other cultivars. At Bethlehem, KNC was significantly affected by planting date and culivars. Plants at optimum and late planting dates produced a higher KNC than for early planting date. Cultivars DKC63-20 and Phb3203 produced a higher KNC, and SAM49 the lowest. At both localities, the cultivar effect was significant, while plant density was non-significant. At Bethlehem, DKC63-20, Phb3203 and ENEGY produced the highest KNC, while SAM49 produced the lowest. However, at Potchefstroom, Phb3203 was superior, while SAM49 was once again the poorer performer in terms of KNC.

At both Potchefstroom and Bethlehem, cob mass was significantly affected by the planting date x cultivar interaction. In general, Maize at optimum planting date produced higher cob mass than those at early and late planting dates. At both planting dates and localities, PAN6017 obtained higher cob mass than ENERGY, DKC63-20, SAM49 and Phb3203. The planting date effect was also the same for the two localities. As expected, optimum plant density produced higher cob mass, followed by low, while high plant density produced the lowest. For the cultivars, PAN6017 proved its dominance and once again produced higher cob mass, while SAM49 produced the lowest.

Hundred (100) kernel mass was significantly affected by the planting date and cultivar effects at Bethlehem. Plants at early planting date produced a higher 100 kernel mass than those at optimum and early planting dates. As for the cultivars, PAN6017 and SAM49 produced the greatest 100 kernel mass, while DKC63-20 produced the lowest. In contrast to Bethlehem, the planting date x cultivar interaction significantly affected 100 kernel mass at Potchefstroom. The trend for optimum and early planting dates was the same. PAN6017 obtained higher 100 kernel mass at both optimum and early planting dates, and DKC63-20 the lowest. However, at late planting date, PAN6017, ENERGY and SAM49 produced a higher 100 kernel mass than both DKC63-20 and Phb3203. The cultivar effect was highly significant for 100 kernel mass at both localities, while plant density was non-significant. PAN6017 and SAM49 produced the highest 100 kernel mass, while DKC63-20 produced the lowest at both localities.

The planting date x cultivar interaction significantly affected grain yield at Potchefstroom. Maize at optimum and early planting dates performed the same, and in those cases, PAN6017 produced the highest grain yield, while SAM49 produced the lowest. At late planting date, PAN6017 proved its dominance over the other cultivars by obtaining higher grain yield. SAM49 remained the poorer performer among other cultivars in terms of grain yield by producing yet another lower grain yield. At Bethlehem, planting date and cultivar effect was significant for grain yield. Early planting date produced higher grain yield, followed by optimum planting date, whilst late planting date produced the lowest. As for the cultivars, PAN6017 produced higher grain yield, while SAM49 produced the lowest. At both localities, grain yield was significantly affected by plant density and cultivars. Cultivar, PAN6017 produced higher grain yield, while SAM49 produced the lowest at both plant densities and localities. In general, optimum plant density resulted in higher grain yield than other plant densities at both localities.

Further field research is needed to confirm these results, and more fundamental research should be done to explain the genotype x environment interaction.

References

ABSTRACT OF AGRICULTURAL STATISTICS., 2004. National Department of Agriculture. Pp. 7-9. Pretoria.

ANDERSON, S.R., LAUER, M.J., SCHOPER, J.B. & SHIBLES, R.M., 2004. Pollination timing effects on kernel set and silk receptivity in four maize hybrids. *Crop Sci*. 44, 464-473.

BENHIL, J., 2002. Climate, water and agriculture: Impacts on and adaptation of agro-ecological systems in South Africa. A case study of the Republic of South Africa. University of Pretoria, South Africa.

Du Toit, W., 2003. Guide for the production of maize in the summer rainfall area. ARC-Grain Crops Institute Publications. www.arc.agric.za/publications.

APPENDIX

Table1A Abbreviated Anova table of yield components and grain yield at Potchefstroom

		Mean squares					
Source	Df	Cob number	Cob length	Cob mass	Kernel number per cob	100 kernel mass	Grain yield
Rep	2	26.94^{ns}	1.43 ^{ns}	6.45 *	5248.3 ^{ns}	13.65 *	7.21 *
Pd	2	1023.92 **	74.05 **	206.79 **	347767.09 **	301.99 **	181.56 **
Pds	2	47.12 ^{ns}	5.03 *	87.12 **	11029.36 *	0.21 ^{ns}	62.45 **
Pd*Pds	4	37.87 ^{ns}	1.89 ^{ns}	0.82 ^{ns}	3375.81 ^{ns}	1.89 ^{ns}	0.54 ^{ns}
Cvs	4	386.25 **	45.98 **	36.64 **	54727.05 **	162.47 **	24.56 **
Pd*Cvs	8	48.31 ^{ns}	3.13 *	32.17 *	10089.29 **	20.93 **	21.54 *
Pds*Cvs	8	15.79 ^{ns}	1.46 ^{ns}	0.98 ^{ns}	1954.36 ^{ns}	2.65 ^{ns}	1.23 ^{ns}
Pd*Pds*Cvs	16	9.75 ^{ns}	1.40 ^{ns}	0.76 ^{ns}	2816.71 ^{ns}	3.63 ^{ns}	0.45 ^{ns}
Error		32.32	1.64	1.56	3124.52	3.25	1.10

Pd = planting date

Pds = plant density

Cvs = cultivars

Pd x Pds = planting date x plant density interaction

Pd x Cvs = planting date x cultivar interaction

Pds x Cvs = plant density x cultivar interaction

Pd x Pds x Cvs = planting date x plant density x cultivar interaction

Ns = non significant

* = Significant

** = Highly significant

Table 2A Abbreviated Anova table of vegetative growth at Potchefstroom

		Mean squares				
Source	Df	Leaf area index	Dry matter yield	Plant height	Flowering (50%)	Physiological maturity
Rep	2	1.02 **	4145.69 ^{ns}	128.56 ns	5.81 ^{ns}	9.07 *
Pd	2	1.02 **	623917.02 **	6989.16 **	449.87 **	1275.23 **
Pds	2	7.91 **	363456.53 **	1251.05 **	811.92 **	2.76 ^{ns}
Pd*Pds	4	0.03 ^{ns}	2242.16 ^{ns}	103.67 ^{ns}	194.92 ^{ns}	3.45 ^{ns}
Cvs	4	3.01 **	28989.20 **	5394.96 **	944.52 **	449.87 **
Pd*Cvs	8	0.17 ^{ns}	3081.45 ^{ns}	526.76 *	130.71 ^{ns}	10.05 **
Pds*Cvs	8	0.07 ^{ns}	5402.78 ^{ns}	86.37 ^{ns}	180.69 ^{ns}	5.14 **
Pd*Pds*Cvs	16	0.13 ^{ns}	2958.80 ^{ns}	93.60 ^{ns}	118.79 ^{ns}	2.03 ^{ns}
Error		0.12	4387.86	161.69	0.39	1.04

Pd = planting date

Pds = plant density

Cvs = cultivars

Pd x Pds = planting date x plant density interaction

Pd x Cvs = planting date x cultivar interaction

Pds x Cvs = plant density x cultivar interaction

Pd x Pds x Cvs = planting date x plant density x cultivar interaction

Ns = non significant

* = Significant

** = Highly significant

Table 3A Abbreviated Anova table of yield components and grain yield at Bethlehem

		Mean squares					
Source	Df	Cob number	Cob length	Cob mass	Kernel number per cob	100 kernel mass	Grain yield
Rep	2	26.67 ^{ns}	0.39 ^{ns}	4.23 ^{ns}	673.40 ^{ns}	17.77 *	2.39 ^{ns}
Pd	2	198.23 **	10.94 **	131.62 **	8045.96 **	224.77 **	97.04 **
Pds	2	26.09 ^{ns}	0.49 ^{ns}	92.95 **	349.49 ^{ns}	2.11 ^{ns}	69.66 **
Pd*Pds	4	20.42 ^{ns}	0.49 ^{ns}	1.11 ^{ns}	2221.18 ^{ns}	2.22 ^{ns}	1.03 ^{ns}
Cvs	4	142.81 **	53.38 **	15.28 **	100550.21 **	300.53 **	8.13 *
Pd*Cvs	8	28.86 ^{ns}	3.96 **	3.76 *	2580.52 ^{ns}	4.84 ^{ns}	1.83 ^{ns}
Pds*Cvs	8	17.67 ^{ns}	1.04 ^{ns}	2.45 ^{ns}	1737.69 ^{ns}	1.500 ^{ns}	1.80 ^{ns}
Pd*Pds*Cvs	16	12.42 ^{ns}	1.09 ^{ns}	1.43 ^{ns}	2016.46 ^{ns}	2.68 ^{ns}	1.19 ^{ns}

Pd = planting date

Pds = plant density

Cvs = cultivars

Pd x Pds = planting date x plant density interaction

Pd x Cvs = planting date x cultivar interaction

Pds x Cvs = plant density x cultivar interaction

Pd x Pds x Cvs = planting date x plant density x cultivar interaction

Ns = non significant

* = Significant

** = Highly significant

Table 4A Abbreviated Anova table of vegetative growth at Bethlehem

		Mean squares				
Source	Df	Leaf area index	Dry matter yield	Plant height	Flowering (50%)	Physiological maturity
Rep	2	0.32 ns	22427.60 *	255.02 ns	5.96 *	3.12 ns
Pd	2	6.81 **	692832.01**	13604.36 **	556.07 **	847.21 **
Pds	2	5.49 *	311816.74 **	272.62 ns	3.82 ns	0.54 ns
Pd*Pds	4	0.66 ns	1986.54 ns	213.78 ns	4.52 ns	2.14 ns
Cvs	4	3.94 *	76970.94 **	852.54 **	168.94 **	390.25 **
Pd*Cvs	8	0.35 ns	1420.94 ns	124.50 ns	2.49 ns	1.35 ns
Pds*Cvs	8	0.09 ns	3268.44 ns	131.10 ns	0.55 ns	2.59 ns
Pd*Pds*Cvs	16	0.05 ns	8051.25 ns	77.12 ns	1.81 ns	1.64 ns
Error		0.18	5666.07	129.58	2.39	2.38

Pd = planting date

Pds = plant density

Cvs = cultivars

Pd x Pds = planting date x plant density interaction

Pd x Cvs = planting date x cultivar interaction

Pds x Cvs = plant density x cultivar interaction

Pd x Pds x Cvs = planting date x plant density x cultivar interaction

Ns = non significant

* = Significant

** = Highly significant