

**INTERGRATION OF MANAGEMENT PRACTICES TOWARDS
IMPROVING HYBRID MAIZE YIELD, QUALITY AND NUTRITIONAL
COMPOSITIONS UNDER RAIN-FED CONDITION**

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DECLARATION

I, Akinnuoye-Adelabu Dolapo, declare that:

- The research reported in this thesis, except where otherwise indicated is my original work, which have not been submitted for any degree or examination at any other university.
- This thesis does not contain data, graphs or other information from other researchers, unless specifically acknowledged as being sourced from other persons.
- This thesis does not contain other persons' writing, unless acknowledges as being sourced from other researchers. Where other written sources have been quoted, then their words have been re-written and duly referenced.



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DEDICATION

This thesis is dedicated to the keeper of my soul (*Almighty God*) who granted me the grace, ability and preserve my life during this study.

GENERAL ABSTRACT

Maize (*Zea mays L.*) is an important staple crop grown under different ecological conditions by both large-scale commercial and smallholder farmers in Southern Africa. The current changes in climatic conditions may propel farmers to shift from their convectional planting windows and harvesting period, which may have resultant effect on the seed yield and quality. Hence, it is important to understand how maize production responds to climate change. This study evaluated interaction of planting date and soil fertility level on maize (*Zea mays L. cv. SC701*) morphological, physiological and yield parameters. Field trials were conducted during the 2014/15 and 2015/16 seasons at two sites under dryland conditions to compare the effects of early season, mid-season and late season planting dates on these parameters under different soil fertility levels. In addition, yield, kernel nutritional value and seed quality were determined in response to different maturity stages. Results showed a significant interaction between planting date and fertiliser application on crop growth and quality. The study indicated that maize production is more sensitive to planting date, which is linked to a lack of optimum temperature for growth than fertiliser application. However, optimum soil fertility can be used to attain a better seed quality under sub-optimal planting date.

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LIST OF ABBREVIATIONS

ARC-ISCW – Agricultural Research Council – Institute for Soil, Climate and Weather

AWS – automatic weather station

CCI – Chlorophyll content index

DAP – Days after Planting

DAS – Days after silking

FAO – Food and Agriculture Organisation

GDD – Growing degrees days

gs – Stomatal conductance

LAI –Leaf area index

SSA– Sub Sahara Africa

WAP– Weeks after planting

CHAPTER 1

GENERAL INTRODUCTION AND OVERVIEW

Rationale for the research

Maize is a highly versatile, potential annual grain crop and third most important cereal in the world in terms of production area (*Shiri et al.*, 2010). It plays an important role (20-25%) in human nutrition and is widely grown throughout the world in a range of agro-ecological environments (*Gerpacio and Pingali* 2007). However, low productivity and quality among rain-fed farmers may be due to suboptimal performance related to management aspects and climatic variability. Although, poor management factor contributed more to low productivity in maize. Production of crops with high vigour seed and tolerant to environment conditions might be a promising approach in meeting the crisis in food demands. Moreover, knowledge about the biochemical and physiological processes that occurred in maize during seed developmental stages will help in choosing optimal planting date to obtain high seed quality for most Southern Africa commonly grown maize hybrids. Factors that influence the yield and quality of maize are stage of maturity at harvest, soil fertility level and availability. Date of planting and nutrient availability affect plant physiological and morphological processes especially during vegetative and reproductive periods whereas stage of maturity at harvest is one of the most important factors that can influence the quality of seeds and its yield (*Aboutalebian et al.*, 2012, *Demir et al.*, 2008). Hence, there are major challenges ahead for seed industries and farmers on how to provide seed that can maximize future crop production in the midst of adverse environmental conditions (*Ceccarelli et al.*, 2010).

Several efforts and researches have been carried out on maize to improve its yield and quality under adverse environmental conditions (*Coulter 2012, Jacob Junior et al., 2014*). However, less precise information is available on effect of maturity stage at harvest on seed quality under adverse environmental conditions. Comprehensive knowledge on effect of maturity stages on seed quality under changing environmental conditions could enable seed producer to overcome the effect of adverse environmental conditions and thereby avoiding severe field seed losses. In addition, it is essential in estimating the appropriate stage when seeds could be harvested with minimal loss in seed viability and vigour. The effect of different planting dates and maturity stages of maize under rain-fed conditions has received very little attention in South Africa. Likewise, the nutritional compositions at each maturity stages in relations to the management practices used is not well documented.

Justification

The resilience of maize, against current weather extremes during its growth and development, is well thought-out to envisage their adaptation to future climate change (*Spollen et al., 2008*). Maize is widely grown throughout the world in a range of agro-ecological environments. The adverse weather conditions associated with suppressed rainfall and higher atmospheric temperatures in large portions of Southern Africa during maize planting season has resulted in severe yield loss and quality (*FAO 2015*). The quality of a seed is a measure of attributes that determine the performance of seeds when planted or stored (*Hampton 2002*) which need to be maintained in the midst of this crisis. However, majority of small-scale farmers in South Africa are rainfall dependent. Reduction in production and seed quality of maize under rain-fed areas is mostly related to sub-optimal conditions of management practice and climatic variability (*Sani et al., 2014*). The average seed yields are lower among small-scale farmers compared to those achieved by commercial farmers who have access to irrigation,

fertilizers, and credit. The responses of a commonly grown hybrid among the farmers to different management practices might also vary. The combined effect of management practices such as planting date, parental soil fertility status and maturity stages at harvest might be of great promises for production of high maize yield and quality (Gaile 2012, Wakene *et al.*, 2014). Production of maize that can maximise seed increase during adverse environmental conditions forecasted is of great concern. In addition, the knowledge of changes in physiological processes of maize during maturation stages under different environmental conditions will give better understanding of improving yield and seed quality of maize hybrids.

Aims and objectives

The aim of this study was to evaluate maize growth and development, yield, quality and nutritional composition in response to varying management practices in KwaZulu-Natal, South Africa.

Research hypothesis

Based on the above propositions, this study hypothesized that significant differences exist between seed quality and yield of maize hybrid harvested at different stages of their seed maturation under different planting dates. In addition, planting dates and fertilizer application was hypothesized to influence yield, quality and nutritional compositions of maize during seed development.

Specific objectives

- To evaluate the effect of planting date and soil fertility level on maize hybrid yield under rain-fed condition.

- To determine response of planting date and maturity stage at harvest in relation to maize yield under rain-fed conditions.
- To study the interactive effect of soil fertility levels and maturity stages at harvest on maize hybrid yield under rain-fed condition.
- To evaluate the interactive effect of planting date and improving soil fertility level on maize germination capacity and vigour.
- To evaluate the interactive effect of planting dates and maturity stages at harvest on maize germination capacity and vigour.
- To determine the interactive effect of fertilizer application at different maturity stages on maize germination capacity and vigour
- To evaluate changes in the seed soluble carbohydrate and protein accumulation during seed maturation under different fertility levels of commonly South African grown maize hybrid.

Structure of thesis

A series of agronomic and laboratory experiments were conducted over two seasons (2014/15 and 2015/16 seasons) to answer the objectives of this study. This thesis consists of individual manuscripts, whereby each manuscript answers to a certain objective of this study. Following a general literature review (chapter 1). Therefore, there was duplication of information in the materials and methods of chapter 3-5.

Chapter 2 is a study of interaction of the management practices on maize seed yield under dry land farming conditions. The chapter was arranged into three sections in which each section addresses the effect of each management factor in relation to seed yield. These are presented as different manuscripts (chapter 2): “*Interactive effect of planting date and soil fertility levels on seed yield maize hybrid*”; (chapter 3) “*Planting date and harvesting stages influence maize*

yield” and (chapter 4)“*Influence of soil fertility and maturation on maize yield under dry land farming conditions*”, respectively. Chapter 5 reports on the effect of mangament practices on maize seed quality under dry land farming conditions. The chapter was also arranged into three sections (chapter 5)“*Effect of planting date and maturity stage on seed quality of SC701 under smallscale farming conditions*” ; (chapter 6)“*Response of maize seed quality to varying planting date and soil fertility under rainfed*” and (chapter 7) “*Soil fertility and harvesting stage affect on maize seed quality under rainfed conditions*”, respectively. Chapter 8 provides insight into how stages of maturity at harvest and soil fertility levels influenced nutrient composition of maize kernels. It contains a manuscript entitled “*assessment of nutritional composition of hybrid maize grain based on soil fertility and maturity stages at harvest*”. Finally, a general discussion, which formed the last and final chapter of this thesis. It offers a holistic discussion, encompassing all the separate studies reported in this thesis. It also highlights major findings, outcomes and recommendations.

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CHAPTER 1

Literature Review

Abstract

Maize is an important food security crop in many parts of the world but due to seasonal changes in temperature and precipitation, its production season varies. This chapter reviews some of the published articles on the importance of planting date and soil fertility on maize seed quality at varying maturity stages. Seed performance is highly dependent on efficient utilisation of soil nutrients by the maternal plant and prevailing environmental conditions during seed maturation. Acquisition of vigour and germinability was expected to vary with environment and planting date. The developmental phases of crops planted at different periods are subjected to different environmental conditions that affect seed quality. Seed germination, vigour and seedling establishment might be influenced by seed composition. It is important to understand the physiological changes associated with seed performance during maturation, such as proline accumulation and seed nutrient content. The literature indicated that early to mid-season planting is advantageous for seed production to attain maximum seed viability and vigour, harvesting should not be too early nor too late. However, there is a knowledge gap with respect to how to deal with seed harvested prior to physiological maturity due to adverse weather conditions.

Keywords: fertilizer, germination, maturity, season and vigour

Introduction

The adverse weather conditions associated with suppressed rainfall and higher temperatures in large portions of Southern Africa during main planting season has resulted in severe yield loss and quality (FAO 2015). The quality of a seed, which is a measure of characteristics or attributes that, will determine the performance of seeds when sown or stored (Hampton 2002) need to be maintained in the midst of this crisis. Seed quality consist of several components such as seed lots viability and germination characteristics, vigour potential, normal embryo and seedling morphology (Finch-Savage and Leubner-Metzger 2006). These components are greatly influenced by the parental growing environment. Viability is related to the capability of the seed to germinate and produce normal seedlings while vigour is the sum of those properties of the seed, which determine the level of activity and performance of seed lot during germination and seedling emergence (Hampton and TeKrony 1995). Early and healthy seedling establishment are essential for optimal growth and maximum yield in cereal crops. In addition, strong and well-developed seedlings can tolerate several environmental stresses during various developmental stages especially in sub-Saharan Africa where greater areas are classified as semi-arid and depend mostly on rain-fed agriculture (Bita and Gerats 2013, Chivenge *et al.*, 2015).

The resilience of cereal crops, especially maize, against current weather extremes, during development, is well thought-out to envisage their adaptation to future climate change (Spollen *et al.*, 2008). Maize is widely grown throughout the world in a range of agro-ecological environments. Its productivity is attributed to its large leaf area, which enhances the leaf carbon exchange rate during its photosynthetic pathway. However, reduction in production and seed quality under rain-fed areas is mostly related to sub-optimal performance in management practice and climatic variability (Sani *et al.*, 2014).

Management practices such as planting date, parental soil fertility status and maturity stages at harvest dictate the quality of maize seed produced (*Nyakudya and Stroosnijder 2014, Saberi 2014, Tittonell et al., 2008*). Hence, there are major challenges ahead for the seed producers on how to provide seed that can maximise yield during adverse environmental conditions forecasted for the future maize production (*Ceccarelli et al., 2010*). To improve maize seed productivity, much attention should be given to the quality of seed planted, stage of maturity at harvest and parental soil fertility status. Identification of high seed quality starts with selecting appropriate variety to suite the environmental conditions, management practices and the end use of the crop.

The physiological quality of seed can be reduced rapidly by unfavourable environmental conditions during maturation and improper time of harvest. Research on planting dates, developmental stages and fertiliser application to improve maize seed quality has been reported (*Ferreira et al., 2013, Kgasago 2006, Saberi 2014*). Seed quality aspects such as developing and improving the quality of seed through improved soil fertility during maturation in varying environmental conditions have received less attention. *Saberi (2014)* carried out an experiment to determine the performance of different maize hybrids to planting dates and explained that late planting resulted in low yield due to limited number of fertile flowers and high temperature. *Otegui and Melon (1997)* concurred that delay planting was generally accompanied by increased temperatures, which markedly decreased the duration of crop growth causing low biomass production, seed set and grain yield. With the current delayed in the onset of seasonal rains and higher atmospheric temperature in parts of Southern Africa, planting early may not be encouraged.

Planting date influences yield all over the world due to differences in weather condition at seeding. The year-to-year variation in weather conditions makes it difficult to predict optimum

planting dates for maize worldwide (*Otegui et al.*, 1995, *Peykarestan and Seify* 2012). Since seed is important in determining yield and quality of the crop harvested, production of crops with high vigour seed, tolerant to environmental stresses might be a promising approach. In addition, knowledge of changes in biochemical and physiological processes occurring during maturation stages under different environmental conditions could give better understanding of improving seed quality of the commonly grown Southern African maize hybrids.

The current paper reviews some of the published articles on the importance of planting dates, soil fertility and maturity stages at harvest on maize seed quality and yield. Specifically, the manuscript set out to highlight the variation in seed quality during maturation. Finally, it focussed on identifying the current gaps in research towards improving maize seed yield and quality as related to planting date, seed maturation, soil fertility and suggest future directions.

Physiology of maize seed quality

Environmental conditions such as temperature, photoperiod, rainfall, solar radiation and soil fertility level determine seed formation processes and development in crops. This varies from high intensity maize growing system (Europe and North America) to low intensity such as Africa and some part of Asia. *Ahmed and Hassan* (2011) carried out an experiment in region of Asia and reported that an increase in temperature during the planting period reduced germination, hindered vegetative growth and delayed the wheat seed formation processes. In addition, seed performance is highly dependent on maternal environmental conditions especially during seed formation and maturation. Its effect is more pronounced on seedling bed causing various tensions like dryness, low temperature, soil or water salinity and many other stresses (*Enayat-Gholizadeh et al.*, 2014).

A minor rise in temperature above the optimum requirement during seed development will cause significant reduction in yield and seed quality. On the other hand, decrease in temperature prolonged the time for assimilates production and translocation into seeds. Since maize has C₄ assimilation system using higher energy to assimilate carbon and have higher water use efficiency than C₃ assimilation system, increase in temperature within the optimum requirement increased water and nutrient uptake in maize. *Whalen* (2014) observed that an increase of 4.2 °C around maize roots increased uptake of phosphorus, copper, and zinc per root dry matter. However, it was not well documented in literatures whether improved soil fertility through fertilizer application could lead to high seed yield and quality in maize during adverse weather conditions.

For better crop development, parental soil fertility status has great significance, thus plant nutritional status may go a long way in determining the seed vigour. The amount of nutrient present in the soil during the cropping season is influenced by leaching, volatilization and denitrification. *Modi and Greenfield* (2010) reported that it was impossible to predict seasonal soil nutrient requirements because of unpredictable seasonal weather conditions and continuous nutrient status assessment in the crop at each season is of great importance. *Wasonga et al.*, (2010) explained that phosphorus uptake requirements depend more on planting environment than variety. Adverse environmental conditions such as low rainfall reduce the response the maize varieties to phosphorus application. Nitrogen (N) and phosphorus (P) are the most important and complex nutrients for seed yield and quality (*Khan et al.*, 2014). However, soils in this region are deficient in N and P nutrients due to continuous cultivation. Since the increase in essential amino acids is proportional to the increase in total nitrogen of maize. Therefore, seeds produced under conditions of low levels of N and P may have poor germination and vigour (*Dornbos* 1995). *Wambugu et al.*, (2012) carried out an

experiment in Kenya under relative low intensity system using on-farm seed production and explained that low soil fertility during maternal plant development and at seed filling resulted in reduced seed quality of progeny. Seed production and quality in maize under high or low intensity planting systems involves a series of complex physiological processes in transition from embryo formation, germination, growth of the seedling and development (*Kucera et al.*, 2005).

Seed development and seed quality

Seed development is a complex and delicate process that requires a coordinated development of embryo, endosperm and seed coat (Baud *et al.* 2008). During this period, physiological quality is acquired and can be hindered by any deteriorative processes such as extreme weather conditions. Seed development can be grouped into five stages: cell division, cell enlargement, deposition of reserves, maturation and desiccation. *Motto et al.*, (2010) reported that in maize endosperm, development had three major phases, which are lag, grain filling, and maturation–desiccation phases. Lag phase occurs few hours after pollination to about 12 days after pollination (DAP). It has four different stages, which are coenocytic, cellularization, cell fate specification and differentiation leading to rapid endosperm expansion. Grain filling phase starts around 12–40 DAP. Biochemically, grain filling involves conversion of imported nutrients, mainly sucrose and amino acid, into starch and storage proteins. Maturation–desiccation phase usually occurs at 70 DAP. The efficient photosynthesis and nutrient accumulation during vegetative phase influences the formation of generative organs and affect yield and quality. *Modi and Asanzi* (2008) observed that during development, seeds accumulate carbohydrates, proteins and lipids in different proportions depending on the species and environmental conditions during growth. Information on the role of soil fertility at different growing environment on seed maturation and quality were not fully explained in literatures.

Seed maturation is a component of seed quality, a prerequisite for successful seedling germination and emergence. During seed development, the sugar and free cyclitol contents decline while dry mass increases sharply, as physiological maturity is attained dipolymeric and carbohydrates that are more complex remain (*Modi and Asanzi* 2008). The amount of carbohydrates accumulated cause changes in seed mass and increase with maturation in the seed. *Yan et al.*, (2014) observed that the potential for seedling germination was largely programmed during the maturation processes. However, it is not clearly reported if improving soil fertility level can boost the germination potential and vigour of seed lots harvested at early maturation stage. In addition, little research has been carried out concerning interaction of soil fertility and maturation in relation to seed quality under different environmental conditions.

Ellis and Pieta Filho (1992) explained that during development, maximum seed germination and vigour might not have coincided with the maximum dry matter accumulation. Previously, *Harrington* (1972) reported that maximum seed viability and vigour coincided with the attainment of maximum seed dry mass or physiological maturity and declined later. *Tekrony and Egli* (1997) explained that maximum seed quality occurred just prior to or around the attainment of maximum seed dry mass. Other studies on seed quality reported that seed quality continues to increase after the end of the seed-filling phase (*Ellis* 2011, *Tekrony and Egli* 1997). Changes in seed mass, vigour and germination percentage during seed development stages can influence the time seeds reach full maturation. (*Carvalho and Nakagawa* (2000) reported that seed quality potential is acquired early in seed development. Acquisition of vigour and germinability is expected to vary with different soil fertility levels and planting dates.

The role of enzymes in seed development and quality

Rainfall has limited crop development and water availability among rain dependent farming system in Southern African. Water stress occurring during reproductive stage of grain crops is detrimental to yield production and quality. The closure of stomata under water stress lead to heat stress and the induction of heat-shock proteins (*De Ronde et al. 1995*). Accumulation of proline has been linked with the physiological and cytoplasmic cell protection. Proline is of special importance throughout the reproductive phase of crop from flower transition to seed development. It functions as stabilising enzymes and helps in removing reactive oxygen species of the macromolecule and organelle structure. Its main role is protection of developing cells from osmotic damage by counteracting the damage effect that may likely occur during desiccation, which spontaneously occurs in reproductive tissues. Since, tissues undergo spontaneous dehydration observed under stressful environmental conditions at late stage of maturation; proline was proposed to give sustainable energy to metabolically demanding processes during this stage (*Lehmann et al., 2010* and *Spollen et al., 2008*). This could be justified by high levels of proline found in developing seeds, embryogenesis and rapid elongation of pollen tube. *Nathalie and Christian (2008)* explained that proline synthesis occurred by two pathways, glutamate and ornithine pathway. Of these two anabolic pathways, glutamate pathway has been generally accepted as the principal route under stressful conditions.

With the current variation in weather conditions, determination of the optimal planting date has been difficult; most crops encounter stressful environmental conditions during the maturation processes. The relationship between fertilization of the parental plant and accumulation of proline in the progeny seed needs more attention. There is a need to understand the rate of proline accumulation during seed development and its variation with parental soil fertility level.

Potential impact of management practices on seed quality

Effect of planting date on maize seed quality

Planting date is a management factor that can be employed to alleviate adverse effect of stressful conditions. Planting date is determined by onset of significant rainfall, optimal soil temperature and humidity of the region. Generally, maize is usually planted in South Africa by October/December, but delay in the onset of rain due to weather conditions variability is making early planting in October less feasible. Maize growth and development are determined mostly by atmospheric ambient temperature, soil water and solar radiation, which vary with planting dates. *Lehmann et al.*, (2010) reported that the soil temperature, its genetic traits and length of the vegetative stage, influences planting date for maize hybrids. Each given maize hybrid has its threshold since this will determine when planting can be carried out. Among the commonly grown maize hybrid by smallholder farmers in Southern Africa is SC701, which was a late maturing variety (138 - 150 days to maturity) with fairly good drought tolerance (ARC 2014). Early planting usually coincides with low soil temperature and water during spring period in South Africa, thereby delay seedling emergence.

Planting seed early while the soil temperature is below the threshold causes seedling damage and retarded development. However, in the presence of adequate heat units, early planting leads to early ground cover and allow efficient usage of soil water through a well-developed root system thus reducing soil evaporation. This will enhance flowering and fertilization processes thereby, increasing the rate of grain filling and seed weight. According to *Idikut* (2013), maximum temperature for seed germination was 30°C, and optimum temperature ranging between 17°C and 30°C produced high seed germination and emergence. *Liu et al.*, (2015) explained that chlorophyll content declined under low temperature and more carbohydrates are

retained in leaves instead of being translocated to the reproductive sink, thereby reducing the yield and quality. Furthermore, many studies on the effect of temperature in maize have shown a strong negative relationship among low temperatures, germination rate, emergence time, and germination uniformity (*Guan et al.*, 2009, *Itabari et al.*, 1993, *Reimer* 2010).

Late planting of maize reduced the estimated heat unit for the plant growth due to fewer days required for the plant to reach maturity. This reduced average assimilates accumulated by the seed leading to low nutrition quality (*Gaile* 2012). Delaying planting until when enough soil water is stored in the soil profile leads to yield reduction. *Pretorius and Human* (1987) explained that the imbalance caused by increase in the duration of the grain filling and decrease in the rate of grain filling led to yield loss. Most popular maize hybrids used by southern Africa farmers are usually late maturing requiring longer heat unit accumulation, planting this variety lately may lead to loss of yield and quality. Currently, maize seed producer is finding the narrow gap between planting too early and planting too late.

Either early planting or late planting could result in lower yield and quality because there is probability that unfavourable weather conditions may occur after or during planting season. *Norwood* (2001) suggested that farmers should plant on more than one planting date to safeguard against unpredicted weather conditions. In addition, *Lauer et al.*, (1999) suggested that seed producers could increase yields and seed quality during a changing climate by adjusting planting dates. However, crops planted at different dates may experience slightly different photoperiods and temperatures and result in differences at each of their developmental stage. This in turn may affect seed germinability, vigour and have significant impact on seed composition. Late maturing hybrids gain greater yield in relatively warm years than early maturing hybrids while the reverse situation occurs in relatively cold years. There are several studies on the influence of the maternal environment during seed development on physiological

mechanisms of different aspects of seed quality, including germinability, vigour and composition. It was reported that interaction of environmental conditions and seed developmental processes limits maximum seed quality acquisition (*Bita and Gerats 2013, Teng et al., 1994, Zhou et al., 2014*). Although some similarities have been observed in terms of high temperature, water stress and short days during seed development are associated with higher germinability (*Walck et al., 2011*). Little information is available with regards to effect of planting date on seed viability and vigour of specific maize hybrid.

Effect of soil fertility on seed nutrient and quality

Maize seed is valuable source of protein (10.4%), fat (4.5%), starch (71.8%), vitamins and minerals. These nutrients content play important role in seedling establishment, plant growth and development. Embryo and endosperm in the seed contain proteins though embryo proteins are superior in quality and quantity. However, protein content improves under optimal nitrogen fertilization.

Soil nutrient availability determines the chemical composition of seeds and their metabolism, which increase its dry mass, thus enhances seed vigour (*Modi and Asanzi 2008*). The vigour of the seed, which depends upon the status of its stored nutrients, is an important determinant of final crop harvest. Seedlings germination and establishment rely on the seedlings ability to utilize stored seed reserves more efficiently (*Bedi et al., 2009*). The chemical composition of seeds may be affected by genetic factors, environmental conditions and soil fertility status. Seedling establishment required successful remobilization of grain stored nutrient acquired during the ripening period in the mother plant (*Leonova et al., 2010, Nadeem et al., 2012a, Mondo et al., (2013)* reported that seed vigour has a high influence on initial crop establishment and development and could have both direct and indirect effects on capacity of plants in

capturing natural nutritive resources. Enhancing source-sink relationship through fertilization may result in higher seed yield and quality. Nitrogen fertilization, which is an essential element for protein synthesis and transport in cereals, influences plant uptake and accumulation of soil nutrients and improves the quality of seed produced (*Barunawati et al.*, 2013). *Hossain* (2014) explained that vigour of aromatic rice seeds produced was affected by application of fertilizer to maternal plant. In addition, *Ottman et al.*, (2000) observed an increase in germination percentage with nitrogen fertilization and attributed the increase to higher grain volume, mass and kernel size of seed. *Subedi and Ma* (2005) reported maximum seed germination, electrical conductivity and seedling vigour index of the maize seed produced under optimal soil fertility level.

Nutrient availability to the maternal plant could potentially affect seed production and seed quality. *Blumenthal et al.*, (2008) explained that nitrogen fertilizer application has a negative effect on maize grain amino acid, increases grain yields and protein concentration, but reduces the biological value of the protein. The nutrient content in seed increases with advance in maturation giving maximum nutrient accumulation and vigour. However, there is a need to carry out research on determining the effect of fertilization and varying planting dates on seed nutrient content of maize hybrids.

Potential impact of maturity stages on seed quality

Seed vigour is highly dependent on stage of kernel maturity at harvest and low seed quality could be due to untimely harvest. For maximum viability and vigour in seeds, harvesting should be done at physiological maturity. Many researchers (*Harrington* 1972, *Henning et al.*, 2011) have recommended harvesting at physiological maturity when qualitative and quantitative seed losses are at minimal. *Borowski et al.*, (1991) explained that seed industry currently harvests

seed at 0.35 to 0.45 g H₂O/g fresh weight and there is a possibility of harvesting seed at higher moisture levels than is currently practiced. Early harvests could help to reduce the pathogen load, diseases and pest attacks during seed development and maturation. Harvesting of maize seed at the milk line when 50% of the endosperm was hard has been proposed by *Andrade et al.*, (2013) but reduction in seed germination and vigour were observed. Early harvest of seed have been characterized with high seed moisture content, immature seed, tendency of faster deterioration and suffer greater mechanical damage during processing due to soft seed coat. Soft seed coat occurs because of the partial development of essential structures of seeds (*Wang et al.*, 2008).

With the current increment in adverse weather condition, the possibility of harvesting maize before it reaches physiological maturity is very high. In addition, there should be ways of getting high seed quality in early harvested seed amid this crisis. The ideal harvesting at physiological maturity may have to shift during harsh weather condition to obtain- maximum seed quality as possible -since the physiological changes that occur during seed development varies with environmental conditions and maturity stages. Therefore, precise period at which maize hybrid attains its maximum seed quality under different planting dates may also vary. In addition, understanding the response of each seed lots at different maturity stages to seed quality under these conditions may boost the knowledge of developing adaptive strategies for high quality seeds in maize.

Determination of seed quality

In order to determine the quality of a seed, four criteria are important, namely; seed purity, seed viability, seed health and seed vigour (*ISTA* 2016). Of these four, seed viability and vigour are

the most important indicators of seed quality, because they indicate the inherent properties of the seed (*Hossain* 2014).

Seed viability assesses the ability of the seed to produce a healthy plant under favourable environmental conditions. High germination percentage is a crucial feature of high quality seed but it usually produces results that overestimate seed performance under less favourable conditions. While, seed vigour is the ability of the seed to emerge under a wide range of environmental conditions and is the most informative indicator of physiological seed quality. Seed vigour is influenced by the genetic constitution of the seed, which expresses the intrinsic properties of the seed (*ISTA* 2012). Metabolic events in seeds depend on the cumulative prevailing environmental conditions and the species characteristics during seed development and maturation. *Powell and Matthews* (2005) observed that seed vigour is dependent on many endogenous and external factors that occur during the seed development on the mother plant, at harvest time and during storage. Therefore, seed yield and quality is mostly influenced by the parental environmental conditions and genetic composition. Several authors have evaluated viability and vigour of maize at different developmental stages. For instance, *Ghassemi-Golezani et al.*, (2011) explained that percentage of maize seed germination increased across seed development stages and reached a peak at the end of grain-filling stage and later decreased after mass maturity. However, attention was not given to the prevailing environmental conditions during the development.

Harvesting at early stages of development when the food reserves are low could lead to small seed size. Although, *Msuya and Stefano* (2010) reported that small seed have more germination capacity but lower seedling vigour than large seed. Explaining that the mechanism controlling seedling germination capacity differ from those that are controlling vigorous seedling establishment. Other environmental factors such as planting dates and soil fertility have great

impact on the seed quality but little has been reported on the effect of fertilization on maize seed viability and vigour at different stages of development under varying planting dates. Although, *Souza and Marcos-Filho* (2001) studied the effect of cropping system and fertilizer application on seed quality and reported that nitrogen fertilizer significantly influences maize seed protein content and consequently improves the seed quality. *Wambugu et al.*, (2013) explained that increase in size, viability and vigour of seed grain harvested under optimum soil fertility is due to large seeds, which contain more food reserves than small seeds because it has capacity to nourish the embryo longer during germination. However, these authors did not explain the effect of improved soil fertility during the maturation processes which could provide better understanding to improve seed quality. Existing body of knowledge has showed that low soil fertility hinders the initial growth of maize, reproductive stage and lead to low yield and seed vigour. This diminishes percentage of emerged seedlings, seedling emergence speed, leaf area, and dry mass accumulation. The effect of improved soil fertility through fertilizer application at varying planting dates and maturity stages is poorly understood under semi- arid conditions.

Fertilizer application facilitates production of enzymes, which is important in metabolic processes of germination and growth (*Ochieng et al.*, 2013). High quality seeds require adequate mineral fertilization. A well-nourished plant has healthier condition to produce seeds with high yield and quality. Thus, providing nutrients for the formation of the embryonic axis and storage organs and influencing capacity of the seed to generating a normal seedling and to attain higher seed mass. The vigour in a seed lot is commonly determined through electrical conductivity, accelerated aging and cold test

Electrical conductivity (EC) determines the physiological potential of seeds by evaluating the degree of cellular membrane damage resulting from seed deterioration damage or due to

immaturity of the seeds. Seed developmental stage at harvesting is one of the major factors influencing EC. Electrical conductivity has the efficiency to indicate seed performance to establishment under a wide range of field conditions. Seeds with lower physiological potential have lower cellular membrane selectivity thereby releasing a greater number of electrolytes. Decreased physiological potential and seed germination are directly related to increased quantities of solutes resulting from a loss of membrane integrity. *Ochieng et al.*, (2013) conducted a study using two sorghum varieties of cold and drought tolerance, seeds produced from sorghum crop with fertilizer application had lower EC values than those without fertilizer application. Electrical conductivity in grain seeds decline with optimum fertilizer application and increase with advance in seed maturity.

Other vigour tests include accelerated aging (AA), which measures the degree of deterioration and is indicative of emergence in the field under adverse condition or longevity in storage (*Powell and Matthews 2005*). Accelerated ageing helps to understand the events that lead to the loss of seed viability. The process of deterioration under AA conditions is similar to what is experienced under normal conditions but the rate of deterioration is faster in AA. The most important environmental factors increasing the intensity and velocity of deterioration are high temperature, relative humidity, seed moisture content and storage temperature. *Otegui and Melon (1997)* reported that AA damages DNA and mRNA causing biochemical deterioration of the stored material and reduces the vigour of seedling. While, cold test is the most used vigour test for maize in predicting field performance during early planting, was developed to simulate adverse field conditions and measure the ability of seeds to emerge under cold soil bed. There has been greater increase in abnormal seedlings due to deteriorate seed lots in the cold test. (*Baalbaki et al.*, 2009). There is need to understand the differences the interaction of

soil fertility status and planting dates on seed quality produced. This will give way to improving seed quality under increment in weather conditions.

Conclusions

There was a consensus that developmental stage of seed at harvest influences the germination characteristics of a seed lot. Seed germination in maize increases across the seed development stages and reaches its peak at physiological maturity. Moreover, it is evident that fertilization can change rates of plant growth, maturity period, phyto-chemical content of plants and seed capabilities. In addition, it determines nutrient uptake and accumulation in maize seeds, thereby enhancing germination and seed vigour. An understanding of physiological processes involved in improving the seed quality of maize under different levels of soil fertility would enhance seed production knowledge for different planting conditions. Literature have shown that early or mid-early planting is better for maize seed production, because the plants have longer growth duration. Their growth and development coincides with favourable environmental conditions, thus facilitating more assimilates to both vegetative and reproductive parts. To attain maximum seed viability and vigour, maize seed should not be harvested too early or too late. However, due to the challenges associated with climate change and differences in bio-resource areas for maize production, it is imperative that more research is undertaken to determine whether the physio-chemical and physiological characteristics at maturity stages of maize seeds are influenced by planting date and plant nutrition.

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CHAPTER 2

Interactive effect of planting date and soil fertility on SC701 maize yield under dry land conditions¹

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Abstracts

The knowledge of relationship between planting dates and soil fertility status will enable grower to increase crop yield during current climatic changes. The objective of this study was to evaluate the interaction of planting dates and soil fertility levels on maize (*Zea mays* L.) yield. Field trials were conducted during the 2014-2015 and 2015-2016 seasons at university of KwaZulu-Natal research farm, Pietermaritzburg, South Africa. A split plot design with four replications was used, consisting of planting dates (early, mid and late planting) as main plot and fertility levels (control, minimal and optimal fertilizer application) as sub plot. Interaction of Planting date \times Fertility level significantly influenced the plant physiological (chlorophyll content, stomatal conductance) the highest occurred in early and mid planted maize during 2014/15 and 2015/16 seasons respectively. Growth parameters (leaf area index, plant height and leaf number) and yield components (ear lengths, thousand seed weight, grain yield and kernel row per ear) from optimally fertilized plants under early planting had the highest during 2014/15 while optimally fertilized plants from mid planting had the highest growth and yield components during 2015/16 season. These parameters improved with increase in fertilization and plants from early planting out yielded other planting dates in warmer season while mid planting had the highest yield in drier season. The frequent dry spell and extreme temperature associated with late planting and in drier season was not mediated by improving the soil fertility status. However, optimal fertilization could only improve plant photosynthetic activity under adequate rainfall and temperature.

Key words: Growth, physiology, temperature, rainfall and yield, *Zea mays*

Introduction

Efficient management of soil nutrient to optimize crop yield is a constant challenge for rain fed farmers in southern Africa. Maize (*Zea mays L.*) is an efficient soil nutrient user grown in diverse agro-ecological zones. Nevertheless, soil fertility decline, remains a widespread problem in Sub Sahara Africa (SSA), affecting continuous cultivation of crops thereby constraining food security in Africa. Bukhsh et al., (2012) reported that more than 50% of the increase in crop production yields are due to fertilizers. Furthermore, Duncan (1975) reported the wide environmental adaptability of maize, as it can be grown in regions with less rainfall of 250 mm and high rainfall of 5000 mm at sea level to 4000 m altitudes. The current climatic change pose additional challenge to maize production through extreme weather conditions leading to uncertainty in planting date.

Rainfall and temperature indices are key parameters that influence the decision of planting date, optimal soil temperature and water usually occur as early as around October / November in South Africa. Early planting lead to early harvest and allows farmers to grow the second season maize for the remaining period of the season and generate more income.

Several studies on effect of planting dates on yield have been conducted and the finding revealed that early planting favoured maize yield production than late planting (Tsimba et al., 2013, Duan et al., 2016). However, less information is available concerning response of a specific hybrid to interactive effect of planting date and soil fertility. Hybrids respond differently to weather conditions, nutrient accumulation and utilization. The understanding of each or specific hybrid to different nutrient and weather condition is therefore necessary for increase in yield. Hence, enhancing food security especially in developing world. Maize SC701 cultivar is one of the commonly grown hybrids by both commercial and smallholder farmers

in southern Africa. The cultivar's traits, which include large ear size, long shelf life, high yield and moderate drought tolerance makes it to be widely, desired (ARC 2014). It is a late maturing cultivar which requires an average of 1028 growing degree days from emergence (V_E) to physiological maturity (R_6) and an average of 6.4 mm/day of water from 12 leaf stage to full dent stage (Darby and Lauer (undated).

In South Africa, 12% of the land is suitable for dry land crop production with only 3% considered truly fertile land, predominantly low in nitrogen (N) and phosphorus (P) (Goldblatt 2009). Similarly, smallholder farmers mostly practice intensive and continuous farming to meet with food demand of the increasing population. This practice had put so much pressure on the soil and led to rapid decline in soil fertility. Improvements in soil and management practices are required to combat food insecurity in Sub-Saharan Africa. Consequently, appropriate use of inorganic resources has been suggested as the most feasible option for addressing the soil fertility crisis in SSA (Nature 2012). Variation in soil fertility measured within planting dates might be due to previous season rainfall distribution where longer period of reduced or increased rainfall lead to high or reduce accumulation of nitrate (Duan et al., 2016). Cherkasov et al., (2010) reported that mineralization of organophosphate and migration of nitrate to mobile forms are influenced by temperature and precipitation. However, the efficient utilization of soil nutrient of 'SC701' maize hybrid for yield production during water deficit at any planting date has not been reported.

With the increasing demands for maize production to sustain the ever-teeming population, clearer understanding of interactive effect of weather conditions through planting date and soil fertility level would be of great importance towards improving maize production. The role of improved soil fertility status with planting date that falls within the periods of water stress was not fully understood. Such inadequacies of vital information limit adoption and implementation

of novel fertility management practices that optimizes yield production in this region. This study focussed on the interactive effect of planting date and soil fertility on maize yield under dry land conditions.

Materials and Methods

Experimental site description

Field trials were conducted at the University of KwaZulu-Natal's Ukulinga research farm (29°37_S; 30°16_E; 775 m a.s.l.) over two consecutive (2014/15 and 2015/16) seasons. Ukulinga research farm is classified as semi-arid with mean annual rainfall of 790 mm received mostly between the months of October and April. The summer months varies from warm to hot with mean annual temperature of 18.4 °C (Smith 2006). The soil at Ukulinga was classified as Sterkspruit Smithfield characterised as shallow brown acidic clayey soils with low organic matter (SCWG 2009). The amount of nutrient base is quite low owing to low Cation Exchange Capacity contributing to nitrogen and phosphorous deficiencies (FAO 2015). Foundation seeds of SC701 maize hybrid of uniform size obtained from McDonalds Seed Company in KwaZulu-Natal, South Africa were planted during 2014/2015 while its progeny was planted during 2015/2016 season. SC701 was used because smallholder farmers in the country commonly use it. In addition, foundation seeds were used to eliminate any previous environmental influence on the crop and to have full parental history. The trials were planted at the onset of the rainy season for three planting dates using the common planting dates usually employed by the smallholder farmers in the country Early planting (November 24 and 20), mid-planting (December 12 and 17) and late planting date (January 21 and 27) for 2014/15 and 2015/16 seasons respectively.

Table 2.1: Physicochemical properties of soil at (0 - 20 cm) before setting up the experiments at Ukulinga site in 2014/15 and 2015/16 planting seasons

Fertility levels	Density (mg/L)	P (mg/L)	K (mg/L)	N (%)	Ca (mg/L)	PH (KCl)	Mg (mg/L)	Mn (mg/L)	Cu (mg/ L)	Exch. Acidity (C mol /L)	Total cations (C mol/L)	Clay (%)	*Soil texture	Organic Carbon (%)
(2014/15) season	1.18	38	424	0.23	1739	4.45	581	27	10.8	0.18	14.72	31	Clayey loam	2.30
(2015/16) Early control	1.11	30	379	0.23	1938	4.80	681	23	7.0	0.11	16.40	31	Clayey loam	2.20
Minimal	1.12	30	453	0.23	1886	4.86	683	38	7.6	0.11	16.30	32	Clayey loam	2.30
Optimal	1.17	36	492	0.22	1799	4.60	687	27	9.97	0.11	15.79	31	Clayey loam	2.30
Mid control	1.13	33	391	0.22	1813	4.82	660	30	8.6	0.14	15.62	29	Clayey loam	2.20
Minimal	1.14	39	407	0.21	1802	4.76	652	28	8.9	0.14	15.54	30	Clayey loam	2.10
Optimal	1.11	45.3	453	0.20	1745	4.65	655	31	9.2	0.16	15.41	31	Clayey loam	2.10
Late control	1.14	44.3	473	0.23	1760	4.73	658	22	8.3	0.19	15.60	31	Clayey loam	2.20
Minimal	1.14	50.3	548	0.23	1760	4.74	665	41	9.5	0.09	15.75	32	Clayey loam	2.30
Optimal	1.14	39.7	462	0.20	1795	4.70	665	38	8.1	0.23	15.90	31	Clayey loam	2.00

Exch.Acidity = Exchangeable acidity

Crop management

Land preparation involved ploughing, disking and rotovating to achieve fine tilth for good seed to soil contact. The herbicide 2-chloro- 2-6-diethyl-N-(methoxymethyl) acetanilide (alachlor) was broadcasted pre-emergence at rate of 2.8 kg/ha. Prior to planting in 2014/15 and 2015/16 seasons, soil sampling was collected from top soil (0-20 cm) randomly and analysed for selected physicochemical properties. It was then analysed for selected physicochemical properties at department of agriculture and environmental affairs, soil fertility and analytical services, KwaZulu-Natal, South Africa (Table 2.1). Based on soil fertility results, fertility treatment consists of nitrogen (N) and phosphorus (P) since the soil was not deficient of potassium (K), control (0 N kg/ha, 0 P kg/ha), minimal (100 N kg/ha, 10 P kg/ha) and Optimal (200 N kg/ha, 20 P kg/ha) respectively. Urea (N) and triple super phosphate granule fertilizer (50% P) were used. For N fertilizer, each level was divided into two equal parts (half was applied at planting and the reminder at 8 weeks after planting). Weeds were controlled manually by hand hoeing. Pesticide was sprayed to control insect pest infestation.

Experimental design and layout

The experiment was a split-plot design with four replications. The main plot comprised planting dates with three levels (early planting, mid planting and late planting dates) and sub-plots comprised fertility levels. Smith (2006) recommended a plant density of 30 000 plants/ha for maize under low (700 mm) rain-fed conditions. This current research had the final plant density to be 26 667 plants/ha. The experimental plot of each planting date was made of six rows (planted 750 mm apart and 500 mm within rows). The sampling unit was made of the four inner rows.

Data collection

Plant growth parameters

Observation on growth parameters *viz.* leaf number (LN) and plant height (PHT) were measured on six randomly selected plants from penultimate rows of each plot. These measurements were taken at eight (V_8), ten (V_{10}) and tasselling stage (V_T) visible leaves from the base of the plant to the tip of the tallest leaf according to Nielsen (2016) and recorded in cm.

Leaf area index (LAI) was measured starting from V_T fortnightly using AccuPAR PAR/LAI Ceptometer (LP-80, Decagon Devices Inc, Pullman, Washington, USA) which used the formula described by *Zarate-Valdez et al.*, (2012) where LAI values were derived from the fractional PAR (fPAR) intercepted by the canopy. Fractional PAR is calculated

$$fPAR = 1 - (PAR_{\text{below}} / PAR_{\text{above}}) \quad \text{Equation 1}$$

where, $PAR_{\text{below}} = PAR$ below the canopy ($\mu\text{mol m}^{-2} \text{ s}^{-1}$), $PAR_{\text{above}} = PAR$ above the canopy ($\mu\text{mol m}^{-2} \text{ s}^{-1}$)

$$\lambda = -\ln(1 - fPAR) / LAI \quad \text{Equation 2}$$

Physiological parameters

Physiological parameters of the plants were measured fortnightly as the plant shifted to V_T . Chlorophyll content index (CCI) was measured using a portable SPAD meter (Model SPAD-502-PLUS chlorophyll meter, Konica Minolta, Ramsey, New Jersey USA) on the adaxial leaf surface. While, stomatal conductance (g_s) was measured from the abaxial leaf surface during

midday (12:00 and 14:00h) using a steady state leaf porometer (Model SC-1, Decagon Devices, USA).

Time to reach 50% tasselling (TTT) and silking (TTS) were recorded as number of calendar days taken to reach 50% TTT and TTS from the date after planting. It was recorded based on the appearance of tassel and silks on 50% of the plant population in each plot and expressed in days, later converted to thermal time using the equation 2 as described by (*McMaster and Wilhelm 1997*)

$$GDD = \frac{(T_{max} + T_{min})}{2} - T_{base} \quad \text{Equation 3}$$

Where, GDD = growing degree days (°Cd), T_{max} and T_{min} = maximum and minimum temperatures, respectively, and T_{base} = base temperature if $T_{min} < T_{base}$ then $T_{min} = T_{base}$, $T_{base} = 10$.

Yield and yield components

Maize ears were harvested at physiological maturity stage at each planting date except in mid and late planting dates of 2015/16 season where dent stage of the maize was harvested due to the invasion of wild pigs. At each harvest six ears were randomly selected in each plot and first ear from the top of the plant was harvested by hand.

The seed moisture content (SMC) was determined by wet weight basis and was calculated by the following formula:

$$SMC = \frac{M1 - M2}{M1} \times 100 \quad \text{Equation 4}$$

Where, M_1 is the mass in grams of the seeds before drying and M_2 is the mass in grams of dried seeds. Thousand-seed weight (TSW) was determined by counting hundred seed from each treatment and multiplying by 10. Harvested ears were placed on benches in the glasshouse under dry conditions and allowed to dry to < 12% moisture content. Yield components such as ear length (EL), ear diameter (ED), number of rows/ear (RN/E), kernel number/row (KN/R) and seed yield were recorded. The length of ear was measured from the base to tip by using measuring rule and mean of six ears were expressed in cm. The weight of the individual ear after drying to uniform moisture content <12% was recorded and the mean of six ears was expressed in grams per ear. The seed yield was calculated as kg/ha whereas the harvest index (HI) was computed as the ratio of seed yield to the total above ground using:

$$HI = \text{Seed yield} / \text{biological yield} \times 100 \quad \text{Equation 5}$$

The same procedure was followed in the second planting season.

Description of statistical analysis

Bartlett's test was done to determine homogeneity of variances for all measured variables. Significant differences at 5% level showed common variance among the planting dates in each season. Hence, data for planting dates were pooled for subsequent analysis for crop phenology and yield components. The test did not show homogeneity of variances for crop growth and physiology across the seasons, thus combined analysis was not done. Data were analysed using split plot design procedure from GenStat® (Version 16, VSN International, UK) statistical package was used. Multiple comparison tests were done using Fisher's least significant difference (LSD) at the 5% level of significance.

Results

Preliminary soil fertility analysis

Results of soil chemical properties showed that carbon (%) for the top 0.2 m layer was 2.0% - 2.3% while N was 0.2% – 0.23%. Based on profile pit description, soil texture is clay-loam with an effective rooting depth of 0.6 m (Table 2.1).

Weather data

The weather data showed differences in the rainfall and temperatures measured across the three planting dates in each season. The weather data for 2014/15 season was consistent with the long-term weather data for Ukulinga site. However, weather data for 2015/16 season deviated a bit with an average temperature increase of 2.3°C (November to March) from the predicted annual mean maximum temperatures for the months. Comparing the two seasons, maximum and minimum temperatures were higher in 2015/16 (28.1 and 15.6°C) than 2014/15 (24.9 and 14.9°C) respectively which were not in uniformity with the long-term maximum and minimum temperatures of 25.6°C and 16.9°C (Fig. 2.1). The plants experienced optimal temperature during early planting and below optimal temperature during late planting at both seasons.

Comparing the rainfall received during the early, mid and late planting dates in the two seasons, 2014/15 season (407.9 mm, 371.6 mm and 267.2 mm) received more uniform distribution of rain than 2015/16 (444.8 mm, 360.7 mm and 208.4 mm respectively) (Fig. 2.1). Almost 80% of rainfall received during 2015/16 was highly concentrated within January-March while the rest was sparingly distributed. The reproductive stage of late planted crop at both seasons fall within more days of dry spell and extreme temperature (Fig. 2.1). The weather data showed more favourable environmental conditions for the growth and development of maize in 2014/15 than in 2015/16 season. However, there were more occurrences of hailstorms

during the late vegetative stage of early planting dates in 2014/15 than 2015/16 season, which substantially reduced the plant leaf area and led to yield loss in both seasons.

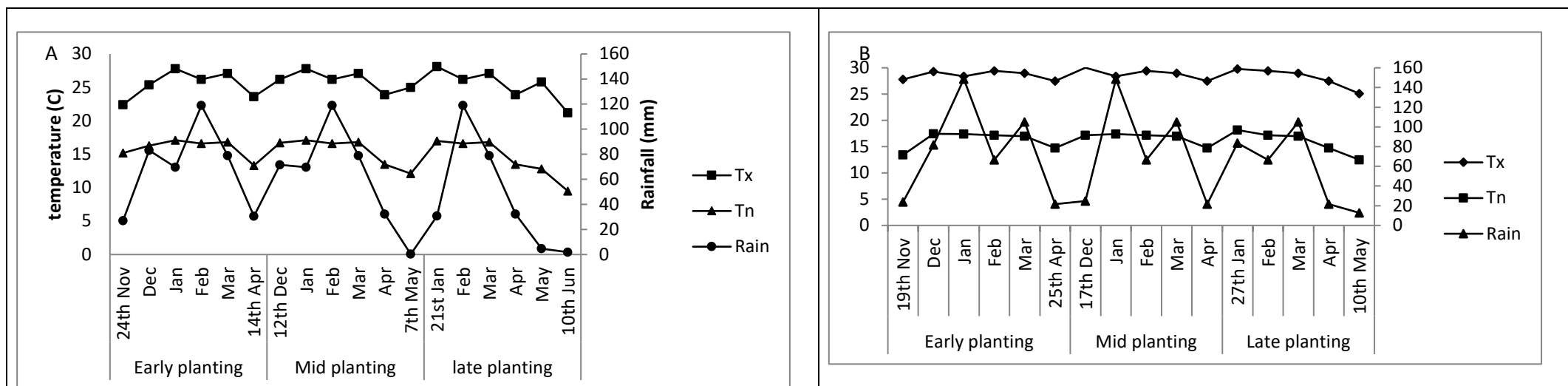


Figure 2.1: Variation in monthly rainfall (rain) and maximum (Tx) and minimum (Tn) temperatures (°C) recorded during the A= 2014/15 and B = 2015/16 planting seasons at

Ukulinga research farm Pietermaritzburg, South Africa

Crop growth and physiology

There were highly significant difference ($P < 0.001$) in plant CCI among the planting dates, fertility levels and weeks after planting (WAP) during 2014/15 season. The interaction effect of planting date \times fertility level significantly influenced ($P < 0.05$) CCI. The plant CCI from early planting date with optimal fertilization had the highest CCI while the least was observed in plant under late planting date with no fertilizer application. The effect of increase in the fertilizer dosage was more distinct on plant CCI under mid planting date while there was little difference in CCI from minimal and optimal fertilized plant under late planting date. During 2015/16 season, CCI was significantly influenced ($P < 0.001$) by planting dates, fertility level and WAP. The interaction of planting date \times fertility level had significant effect ($P < 0.001$) on the plant CCI. The highest plant CCI was recorded in plant under mid planting date while the least was from plant under late planting. The plant CCI from minimal and optimal fertilized conditions performed similarly towards end of grain filling in each planting date. Also, CCI increased with application of fertilizer and decreased across WAP (Fig. 2.2).

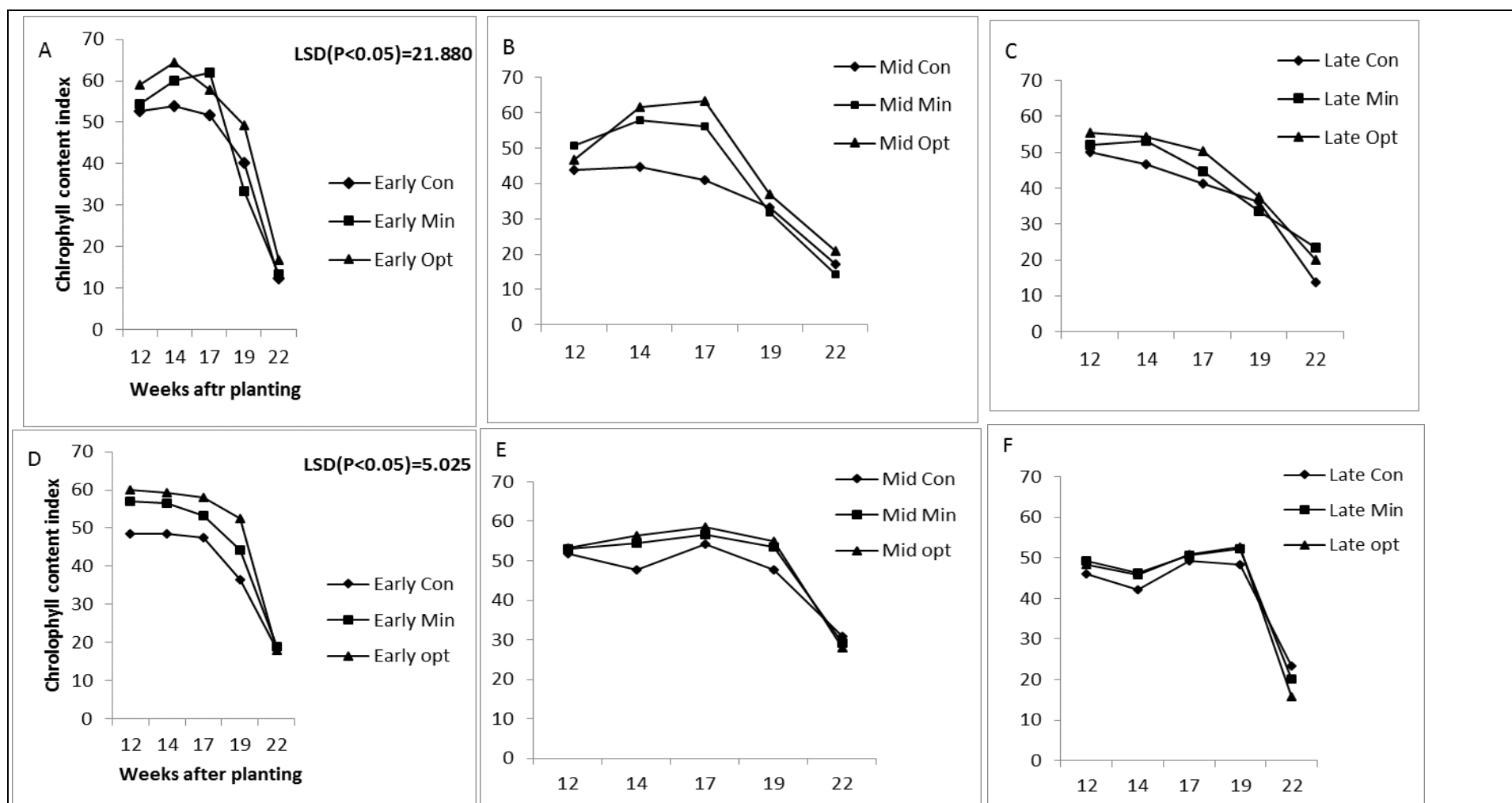


Figure 2.2: Leaf chlorophyll content index under (A and D) early, (B and E) mid and (C and F) late planting dates in 2014/15 and 2015/16 seasons respectively. Early = early planting, Mid = mid planting and Late= late planting date. Con = no fertilizer application, Min = minimal fertilizer application and Opt = optimal fertilizer application

Stomatal conductance (gs) was significantly influenced ($P < 0.05$) by planting date. Highly significant variation ($P < 0.001$) were observed in gs among the fertility levels across WAP and their interactions during 2014/15 season. Stomatal conductances increased with increased rate of fertilizer rate. Plants under early and mid planting dates performed similarly ($225.0 \text{ mmol m}^{-2} \text{ s}^{-1}$ and $225.6 \text{ mmol m}^{-2} \text{ s}^{-1}$) while late planting had the lowest stomatal conductance ($185.3 \text{ mmol m}^{-2} \text{ s}^{-1}$). During 2015/16 season, significant variation ($P < 0.05$) in gs occurred among planting dates, weeks after planting, fertility levels and their interactions. Stomatal conductances from plants under mid planting date had higher gs followed by plants from early planting while late planting had the least gs. Increase in fertility levels from no fertilizer to optimal fertilizer application enhanced the plant gs across WAP (Fig. 2.3).

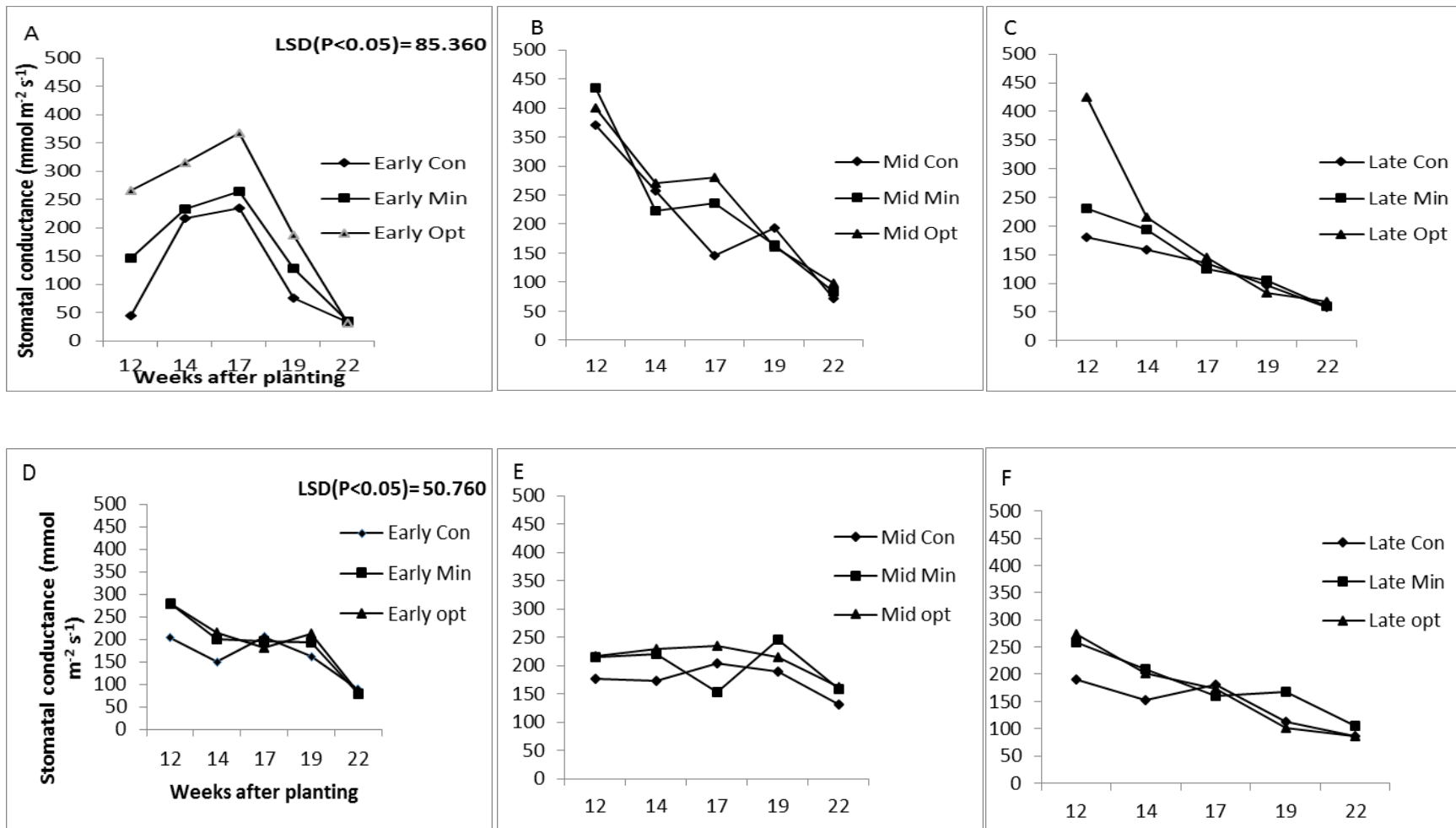


Figure 2.3: The leaf stomatal conductance under (A and D) early, (B and E) mid and (C and F) late planting dates in 2014/15 and 2015/16 seasons respectively. Early = early planting, Mid = mid planting and Late= late planting date. Con = no fertilizer application, Min = minimal fertilizer application and Opt = optimal fertilizer application

The plants leaf area index were significantly influenced ($P < 0.001$) by planting dates, fertility levels, WAP and their interactions during 2014/15 season (Fig. 2.4). Leaf area index increased with increased rate of fertilizer and plants under early planting was 3.2% higher in LAI than those plants from mid planting dates while late planting had the lowest LAI. Leaf area index decreases across WAP which might be due to leaf senescence. During 2015/16 season, LAI was significantly influenced ($P < 0.001$) by planting dates, fertility levels, weeks after planting and their interactions. The highest LAI was observed in plant under mid planting date which was 21.8% and 42.3% higher than LAI in plant from early and late planting dates respectively. Also, LAI improved with increase in application of fertilizer (Fig. 2.4).

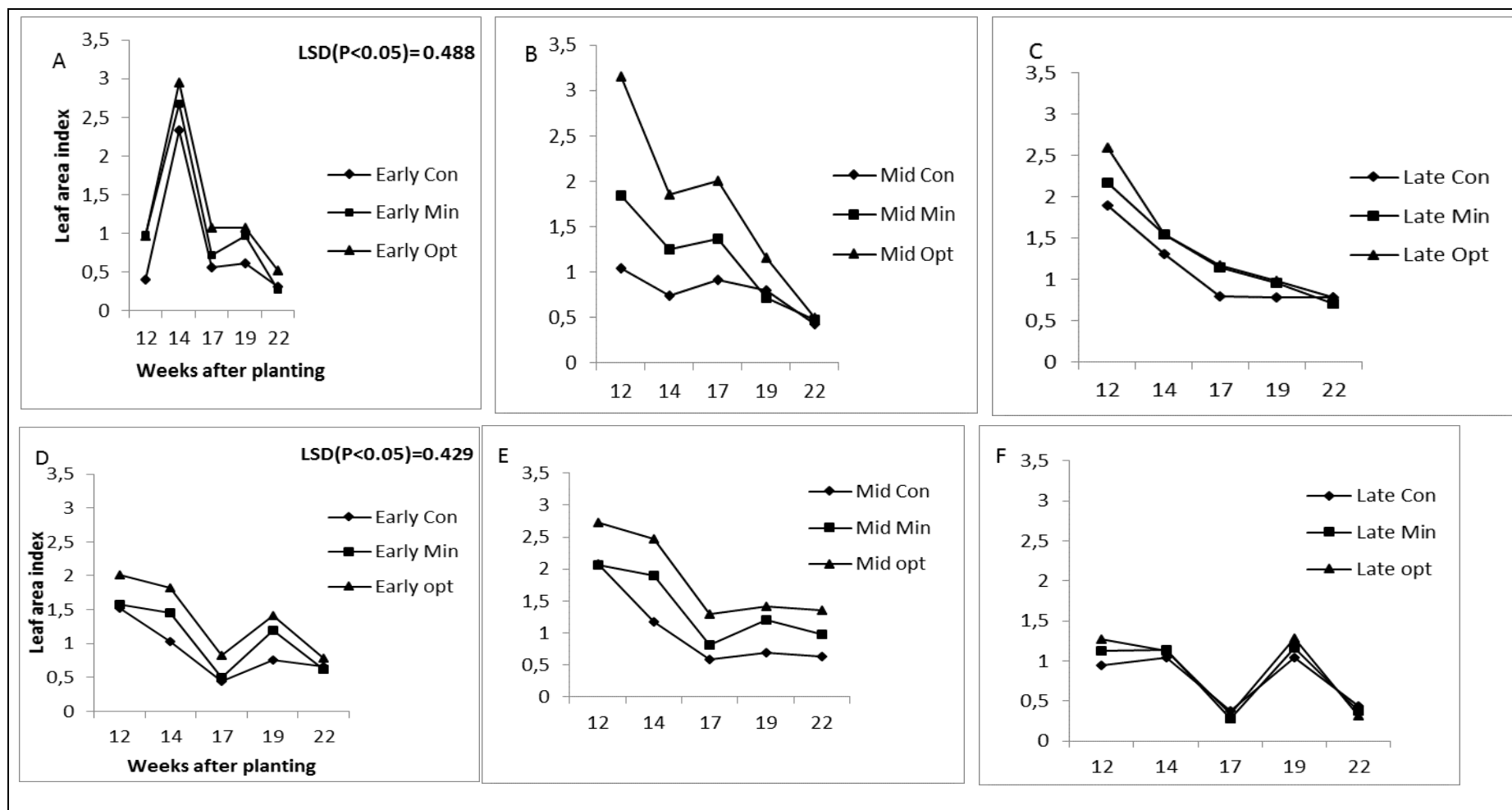


Figure 2.4: The leaf area index of maize under (A and D) early, (B and E) mid and (C and F) late planting dates in 2014/15 and 2015/16 seasons respectively. Early = early planting, Mid = mid planting and Late= late planting date. Con = no fertilizer application, Min = minimal fertilizer application and Opt = optimal fertilizer application

Plant height and leaf number obtained in 2014/15 were strongly influenced ($P < 0.001$) by planting date, fertility level and weeks after planting (Fig. 5 and 6). Also, the interaction of planting date \times fertility level were significantly differences ($P < 0.05$) with regards to leaf number (Fig.2.6). No significant interactions ($P > 0.05$) were observed in plant height and leaf number for planting date \times fertility level \times WAP. Similar results were observed in 2015/16 where plant height and leaf number were strongly influenced ($P < 0.001$) by the planting dates, fertility levels and weeks after planting. The interaction of planting date and fertility level were significantly different ($P < 0.05$) with regards to plant height (Fig. 2.5). During 2014/15 season, the highest plant height and leaf number were observed under optimally fertilized soil and at early planting across weeks after planting. Plant height under optimally fertilized conditions were 12% and 5% higher than the plant height under no soil fertilization and minimal soil fertilization conditions respectively. In addition, plant height from early planting was 34% and 10% higher than those plants under late and mid planting dates (Fig. 2.5). This trend was different during 2015/16 season, where increase in plant height and leaf number favoured mid planting date by an increment of (3.65% and 8.5%) and (17.7% and 13.9%) relative to early and late planting respectively. The plant height and leaf number observed under optimally fertilized conditions were (16.2% and 5.3%) and (7.7% and 1.5%) higher than no fertilized and minimally fertilized conditions respectively (Fig. 2.5 and 2.6). Overall, plant height and leaf number obtained during 2014/15 planting season were 37.8% and 11.4% higher than those observed during 2015/16 season.

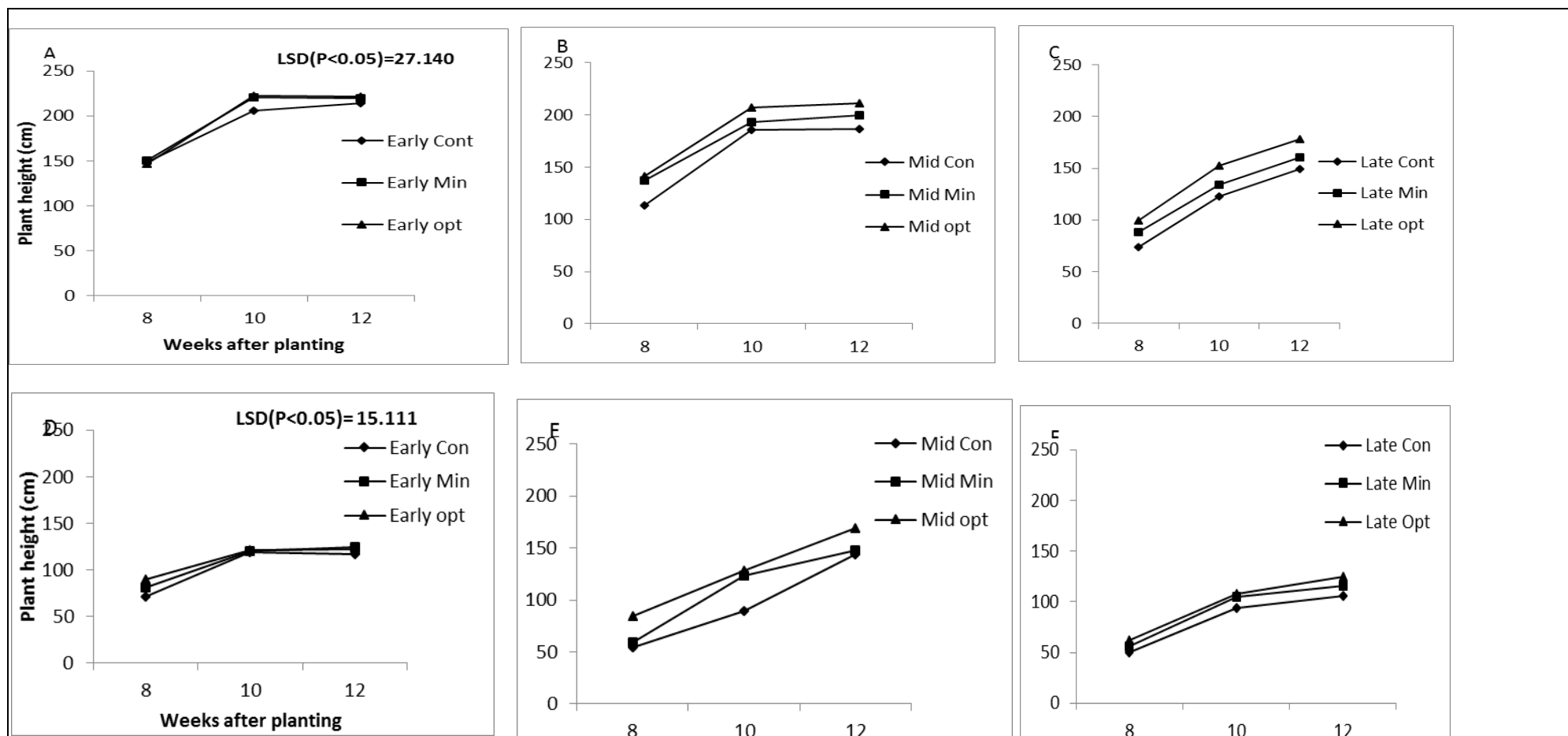


Figure: 2.5 (A-C) Plant heights under different soil fertility conditions during 2014/15 and (2D-F) plant heights under different soil fertility conditions during 2015/16 seasons. Early = early planting, Mid = mid planting and Late= late planting date. Con = no fertilizer application, Min = minimal fertilizer application and Opt = optimal fertilizer application

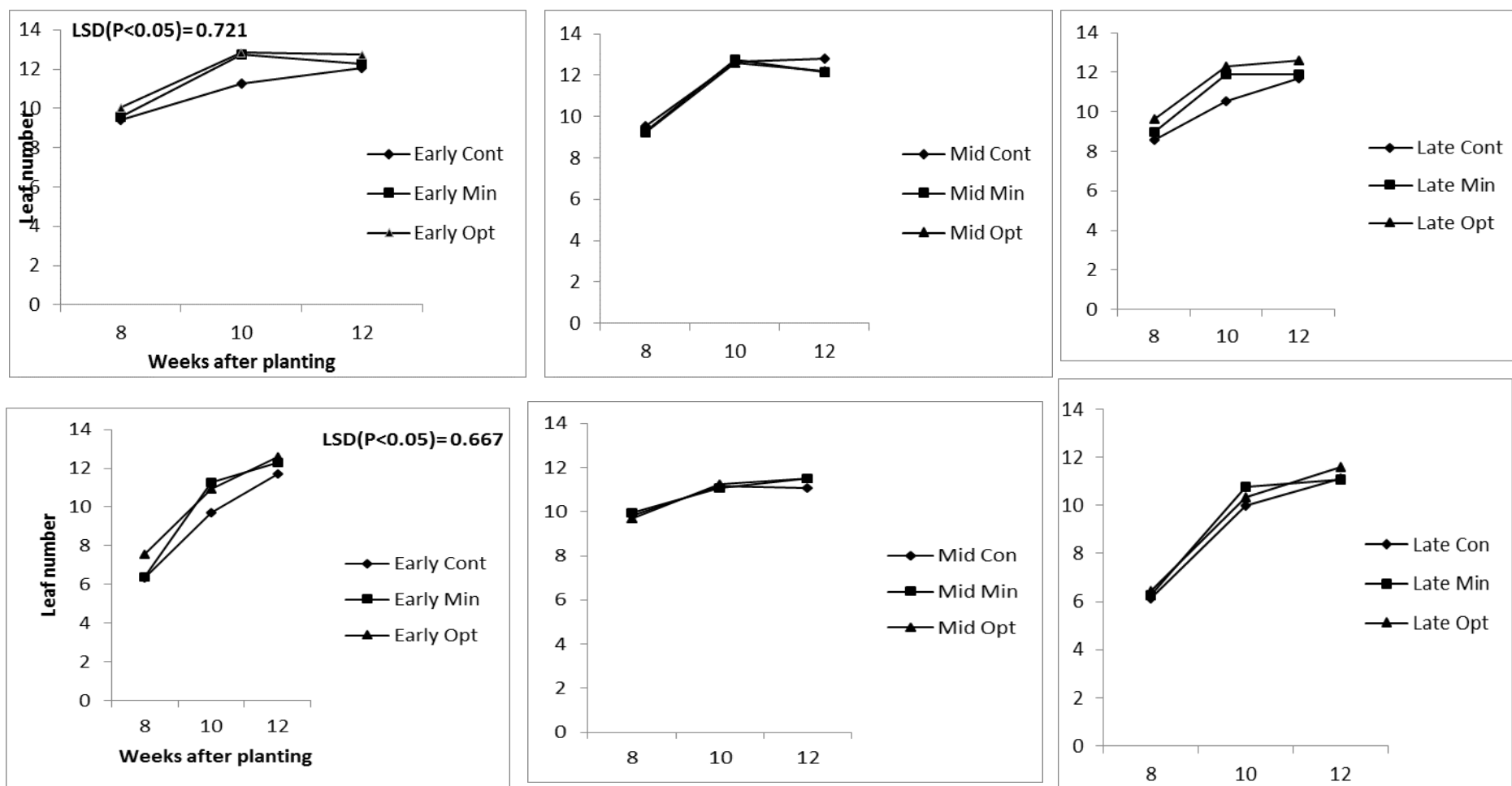


Figure 2.6: Plant leaf number under different soil fertility conditions during 2014/15 and (2D-F) plant heights under different soil fertility conditions during 2015/16 seasons. Early = early planting, Mid = mid planting and Late= late planting date. Con = no fertilizer application, Min = minimal fertilizer application and Opt = optimal fertilizer application

Crop phenology

The time to reach 50% tasselling and silking were significantly affected ($P < 0.001$) by planting dates (Table 2.2). The fertility levels significantly influenced ($P < 0.05$) the time to reach 50% silking in maize. Time to reach 50% tasselling and silking were significant affected by the interactions of planting dates \times fertility levels and planting dates \times fertility levels \times seasons. During 2014/15 season, application of fertilizer prolonged the time to accumulated heat units for tasselling and silking at different planting date. This was contrary in 2015/16, increasing the rates of fertilizer application shortened the accumulated heat unit required for tasselling and silking than under no fertilizer application except at mid planting date where fertilizer application only increased the time required to accumulate heat units for tasselling and silking (Table 2.2). It was observed that under water deficit conditions, application of fertilizer shortened the time require to accumulate heat unit for flowering as observed during 2015/16 season especially under early and late planting but, reverse condition occur during favourable weather condition (2014/15 season).

Table 2.2: Phenological stages of SC701 maize grown under different planting dates and fertility levels during the 2014/15 and 2015/16 seasons. Values in the same column sharing the same superscript letter are not significantly different ($P < 0.05$).

Planting dates (P)	Fertility levels (F)	TTT (°cd)		TTS (°cd)	
		2014/15	2015/16	2014/15	2015/16
Early	Control	846.10b	951.00c	918.00bc	1011.90e
	Minimal	881.80c	899.00bc	958.40de	966.90d
	Optimal	893.40cd	828.00b	972.40e	961.90d
Mid	Control	822.00ab	825.00b	896.30ab	889.10b
	Minimal	891.20cd	829.00b	939.90cd	895.90b
	Optimal	908.40d	877.00bc	976.00e	927.40c
Late	Control	810.90a	888.00bc	884.30a	975.50d
	Minimal	820.90ab	640.00a	891.70a	836.10a
	Optimal	873.60c	681.00a	920.10c	839.30a
LSD values $P \times F$		25.940	103.700	22.520	28.470
LSD values P^1		23.460		6.130	
F.test		$P < 0.05$		$P < 0.05$	
LSD _($P < 0.05$) F^1		34.980		10.050	
F.test		$P > 0.05$		$P < 0.05$	
LSD values Seasons (S) ¹		26.250		8.640	
F.test		$P > 0.05$		$P > 0.05$	
LSD values $P \times F^1$		52.640		14.960	
F.test		$P < 0.05$		$P < 0.001$	
LSD values $P \times F \times S^1$		75.410		23.290	
F.test		$P < 0.05$		$P < 0.05$	

¹ = Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons for the three planting dates TTT and TTS = time to reach 50% tasselling and silking respectively.

Yield and yield components

The interaction of planting dates \times fertility levels had significant effect ($P < 0.05$) on the total biomass and harvest index obtained in 2014/15 planting season. The increase in N and P fertilizer application improved the total biomass and harvest index at each planting season though much increase was observed under early planting (Table 2.3). The highest biomass accumulation was obtained in plant with optimally fertilized conditions under early and mid-planting dates. During 2015/16, interaction of planting dates \times fertility levels had no significantly influence ($P > 0.05$) on biomass accumulation but significantly influenced the plant harvest index. Similarities were observed for harvest index at minimally (51.34%) and optimally fertilized conditions (52.47%) under mid planting dates. In addition, plants from no fertilized and minimally fertilized conditions under late planting date had similarities in their harvest index observed (Table 2.3). Minimal application of fertilizer had little or no effect on harvest index at late planting date. Overall, interaction of planting dates \times fertility levels significantly influenced ($P < 0.05$) the biomass accumulation across the seasons. The interaction of planting dates \times fertility levels also had highly significant effect ($P < 0.001$) on harvest index. Biomass production was higher in 2014/15 compared to 2015/16 season.

Table 2.3: The interactive effect of planting dates and fertility levels on total biomass and harvest index of SC701 maize during 2014/15 and 2015/16 seasons

Treatments			TB (t/ha)		HI (%)	
Planting dates (P)	Fertility (F)	level	1 st year	2 nd year	1 st year	2 nd year
Early	control		9.97bc	7.97a	42.90a	43.94c
	minimal		12.05c	9.33a	50.34bc	51.10de
	optimal		15.41d	12.27b	58.50d	55.44e
Mid	control		7.71ab	7.83a	42.13a	47.12cd
	minimal		12.00c	10.45b	53.71cd	51.34de
	optimal		16.71d	10.76b	50.57bc	52.47de
Late	control		5.96a	6.26a	39.62a	21.55a
	minimal		7.92ab	7.78a	44.13ab	21.82a
	optimal		8.67b	8.54a	42.09a	30.45b
LSD values			2.400	1.631	6.741	6.444
F.test			(P<0.05)	(P>0.05)	(P<0.05)	(P<0.05)
P ¹			(P<0.001)		(P<0.001)	
LSD values			0.797		2.759	
F. test F ¹			(P<0.001)		(P<0.001)	
LSD values			0.970		2.472	
F.test Year(Y) ¹			(P<0.001)		(P<0.001)	
LSD values			0.670		1.987	
PD × F ¹			(P<0.05)		(P<0.001)	
LSD values			1.507		4.153	
PD × F × Y ¹			(P<0.05)		(P>0.05)	
LSD values			2.021		5.772	

Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons yield components for the three planting dates respectively, TB = total biomass, HI = harvest index

Results of yield components (grain yield, thousand seed weight, ear length and kernel row number/ear) over the two planting seasons showed much variability between seasons, fertility levels and planting dates (Table 3.4). During 2014/15 season, the interaction of planting dates \times fertility levels had significant influence ($P < 0.05$) on ear length, grain yield, kernel row/number and kernel row/ear. In addition, highly significant interaction ($P < 0.001$) occurred between planting dates \times fertility levels regarding thousand seed weight. However, the interaction of planting dates \times fertility levels had no significant effect ($P > 0.05$) on ear diameter and seed moisture content. The ear lengths, thousand seed weight, yield and kernel row/ear improved with increase in fertilizer application in each planting date. Early planting had the longest and highest ear length, thousand seed weight, grain yield and kernel row/ear followed by mid planting while the least were recorded under late planting date. Fertilizer application had no effect on kernel number/row under late planting date. During 2015/16 season, the interaction of planting dates \times fertility levels had significant influence ($P < 0.05$) on grain yield, ear length, kernel row/number and thousand seed weight. However, no significant interaction was observed ($P > 0.05$) with regards to other yield components. Plants from no fertilized conditions had the lowest thousand seed weight and grain yield. There were no statistical differences in thousand seed weight of maize harvested under minimal and optimal fertilizer conditions at each planting dates except at late planting. Overall, the interaction of planting dates \times fertility levels had significant effect ($P < 0.001$) on thousand seed weight, yield as well as ($P < 0.05$) kernel number/row (Table 2.4).

Table 2.4: The interactive effect of planting dates and fertility levels on yield components of SC701 maize during 2014/15 (1st year) and 2015/16 (2nd year) seasons

Treatments		EL (cm)		ED (cm)		TSW (g)		Y (t/ha)		KN/R		KR/E		SMC	
Planting dates (P)	Fertility levels	1 st year	2 nd year	1 st year	2 nd year	1 st year	2 nd year	1 st year	2 nd year	1 st year	2 nd year	1 st year	2 nd year	1 st year	2 nd year
	(F)														
Early	control	21.48ab	18.75a	7.81a	7.38a	427.6b	508.20ab	3.76cd	3.44bc	28.88a	27.87a	11.88a	11.17a	24.7a	27.87a
	minimal	25.68cd	20.38b	8.06a	8.00a	639.10c	696.20c	4.17d	4.17cd	47.75b	31.50b	12.88bc	12.67a	23.3a	31.50a
	optimal	29.00f	22.85b	8.63a	8.44a	698.40c	766.50c	5.83e	4.96de	51.12b	39.00b	13.38c	12.08a	21.2a	39.00a
Mid	control	18.88a	20.62b	7.50a	7.69a	431.60b	592.80b	2.34ab	3.67bc	36.75b	26.50a	12.00a	12.17a	23.2a	26.50a
	minimal	26.25de	23.00b	8.00a	8.31a	670.30c	696.20c	4.42d	4.96de	46.25b	34.62b	12.58ab	12.42a	21.9a	34.62a
	optimal	28.50ef	24.75b	8.38a	8.50a	689.10c	697.80c	5.76e	5.35e	49.75b	38.50b	12.29ab	12.75a	24.2a	38.50a
Late	control	20.13a	13.38a	6.94a	6.69a	338.5a	462.50a	2.06a	1.69a	34.50b	18.00a	12.58abc	11.79a	26.9a	18.00a
	minimal	22.95bc	15.50a	7.5a	7.00a	386.7ab	429.80a	3.02bc	2.07a	43.25b	20.50a	12.08abc	12.17a	24.1a	20.50a
	optimal	23.40bc	17.25a	7.69a	7.50a	408.50b	512.20ab	3.94d	3.28b	41.75b	22.50a	12.17abc	12.37a	26.9a	22.50a
F.test P × F		P<0.05	P<0.05	P>0.05	P>0.05	P<0.001	P<0.05	P<0.05	P<0.001	P<0.05	P<0.05	P<0.05	P>0.05	P>0.05	P>0.05
LSD values P × F		2.688	3.261	0.634	0.758	64.490	85.22	0.814	0.870	6.533	6.095	0.807	1.648	5.942	6.095
P ¹		P<0.001		P<0.001		P<0.001		P<0.001		P<0.001		P>0.05		P<0.001	
		0.955		0.309		31.690		0.471		2.937		0.774		1.439	
F ¹		P<0.001		P<0.001		P<0.001		P<0.001		P<0.001		P>0.05		P>0.05	
		1.472		0.377		36.510		0.326		2.348		0.543		2.046	

Year ¹	P<0.001	P>0.05	P<0.001	P<0.05	P<0.001	P<0.05	P<0.001
	0.913	0.179	25.300	0.250	2.349	0.275	2.205
PD × F ¹	P>0.05	P>0.05	P<0.001	P<0.001	P<0.05	P>0.05	P>0.05
	2.207	0.586	57.350	0.608	4.111	1.007	3.114
PD×F×Y ¹	P>0.05	P>0.05	P>0.05	P<0.05	P>0.05	P>0.05	P>0.05
	2.863	0.683	76.630	0.785	6.303	1.139	5.501

EL=ear length, ED = ear diameter, TSW = thousand seed weight, Y= grain yield, KN/R = kernel number/row, KR/E= kernel row/ear, SMC= seed moisture content. 1 = Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons yield components for the three planting dates respectively.

Discussion

Previous studies have found out that the weather conditions such as temperature and distribution of rainfall during maize growth and development determined effectiveness of the applied fertilizer and nutrient uptake (Fageria and Moreira 2011). However, the current study observed that optimal soil nutrition could only maintain maize productivity during warmer season whereas under severe water stress improving the soil nutrition through fertilizer application will cause more harm to the plant growth and yield production.

The plant growth and physiological parameters measured (PHT, LN, LAI, CCI and gs) as observed in this study had the highest performances under optimally fertilized conditions during 2014/15 season. This indicated that nutrients uptake through fertilization was more effective during favourable growing conditions. Plant height increased slowly in drier season and as well as in late planting due to detrimental effect of dry spell on height increment. During the drier (2015/16) season, water deficit condition adversely affected number of leaves and leaf area due to poor leaf expansion and defoliation, which hindered the efficiency of leaf area to intercept light. Reduction in the rate of light interception resulted in decline of the photosynthetic activity.

Decline in leaf chlorophyll content and stomatal activity might be responsible for lower biomass and yield production in late planting date. In addition, rise in leaf temperature caused by high atmospheric temperature under stressful conditions (2015/16 season) might have inhibited the enzymatic activity and reduced the plant photosynthesis. Anjum et al., (2011) attributed the decrease in photosynthetic rate under stressful conditions to dehydration of mesophyll cells, which altered the activities of enzymes that are involved in the mechanism of photosynthesis. It might have changed the gas exchange characteristics causing reduction of

plant water use efficiency. This study showed high efficiency of fertilization on plant growth and development under well-distributed rainfall than under stressful growing conditions. Optimal temperatures and frequent distribution of rainfall in 2014/15 season enhanced fertilizer application through reducing leaching and better adsorption (McNeill et al., 2005). This had positive effect on the ear lengths, thousand seed weight, yield and kernel row/ear as it improved with increase in fertilizer application during 2014/15 season.

The significant reduction in the accumulated heat unit required to attain tasselling and silking stages with increment in fertilization during 2015/16 season could be due to low rainfall received. This led to dry soil during the early vegetative stage of maize in early and late planting dates. In addition, nitrogen fertilizer released free ammonia, which have high affinity for water. Competing for the limited water around the plant dry soils might have impaired the root water uptake causing severe stress to the plant compared to plants under no fertilized conditions. Leitner et al., (2014) reported that stress during the reproductive stage increase the period between tasselling, silking, and widening the anthesis-silking interval.

The major yield components that were influenced by climatic conditions and soil fertility were grain yield, thousand seed weight and kernel row/ear. Subsequent environmental conditions after the initiation of reproductive growth influence the floral development hinder or improve grain filling and final seed weight. This might be due to alteration of carbohydrate metabolism in various parts of the pollen during its development (Zinselmeier et al., 1999). In addition, Everaats and Van Beusichem (1998) explained that length of the planting season and environmental conditions could influence crop nutrient requirements and uptake.

The effectiveness of fertilization was generally higher during warm season than in dry season. Thousand seed weight was greatly determined by climatic conditions; drop in temperature

during the late grain filling caused the reduction in thousand seed weight at late planting which experienced dry spell compared to early and mid-planting dates. Thus, the magnitude of variation in mobilization of seed reserves varied with planting dates.

The increase in grain yield at optimally fertilized soil conditions under early and mid-planting in 2014/15 and 2015/16 seasons respectively might be due to the efficient utilization of the applied soil nutrients that improved the plant vegetative growth and development. Haruna and Nkongolo (2013) attributed variations in grain yield to differences in agro-ecological conditions, degree of variability of seasonal rainfall, length of growth period and land use.

This study provided evidence that the distribution of rainfall at each planting date has a strong influence on nutrient utilization for plant growth and yield production. As observed, stronger responses to N and P fertilization occurred in 2014/15 season where temperatures were optimum and rainfall was evenly distributed. This study was agreed with Xie et al., (2013) who explained that the effectiveness of nitrogen applications and weather effects on maize yield were influenced by complex interactions between crop, weather and soil. However, Karim and Rahman (2015) suggested that adequate nutrition might be important for maintaining high plant productivity in drought stress under arid and semi-arid environment. Optimal fertilization had little effect on the grain yield during the drier (2015/16) season as compared to warmer (2014/15 season) as well as during late planting date. Hence, minimal application rates of fertilizer during drier season would give similar yield output as optimal application. The last month in maize grain filling are crucial for dry matter accumulation, drop in temperature during this period would directly reduce yield as observed in plants under late planting.

Conclusions

Management of the maize planting date and soil fertility could be an effective way to achieve sustainable agriculture under future climate conditions. Late planting of maize experienced low rainfall, and drop in temperature causing low yield irrespective of the soil nutrient status. Supplemental irrigation may be required to attain maximum yield. During early planting season, planting early out-yielded other planting dates with regards to maize growth, development and yield production but during drier planting condition as observed in 2015/16 season, mid planting had the highest maize growth and yield production. Planting maize lately (January) irrespective of the soil fertility status would result in lower yield. The frequent dry spell and extreme temperature associated with late planting might not be mediated by improving the soil fertility status because nutrient acquisition by roots might be inhibited thereby causing deleterious effects on maize yield. However, balanced fertilization could only improve photosynthetic activity under warmer planting season.

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CHAPTER 3

Planting dates and harvesting stages influence on maize yield under rain-fed conditions¹

¹(Accepted to the Journal of Agricultural Science)

Abstract

Understanding the challenges associated with variation in weather conditions and stages of maturity in maize are essential for farmers to achieve continuous production under climate changes. This research evaluated the interactive effect of planting date and stages of maturity at harvest on maize yield (*Zea mays L.*). Field trials were conducted during the 2014/15 and 2015/16 seasons at university of KwaZulu-Natal research farm Pietermaritzburg, South Africa. Planting dates comprised of early (November), mid (December) and late (January) planting dates While, harvesting occurred at milk stage, dent stage and physiological maturity. Split plot design with four replications was used. The main plot and sub-plot consisted of planting dates and harvesting stages respectively. Response of maize to planting dates and harvesting stages was determined by variables of plant physiological growth and yield parameters. Significant differences in growth and physiological parameters were more obvious in 2015/16 season, which was a drier season than 2014/15. Early and mid-planting had positive effect on parameters measured at both seasons. However, mid planting date favoured maize growth and yield more in drier season. The interaction of planting dates and harvesting stages significantly influenced grain yield, thousand seed weight, ear length and diameter. Thousand seed weight, ear length and diameter obtained at dent stage under mid planting outperformed its counterpart from physiological maturity under late planting. With the increase in climate variability, there is high risk that maize planted lately would have lower yield and might not attain physiological maturity. However, maize harvested at dent stage under early and mid-planting dates gave substantially high yield.

Keywords: Maturation, production season, weather, yield

Introduction

The weather conditions at the time of planting have a profound influence on the potential profitability of maize especially under rain-fed cultivation. Hence, planting date is one of the most important management practices that influence crop yield through seedling establishment and development. Planting date has direct influence on day and night temperature, light intensity, photoperiod and soil moisture, which affect crop growth duration and harvesting period. However, optimum planting date varies across regions and differences in planting dates expose crop to different stress factors. Existing body of knowledge have shown that maize yield potential reduced with delay in planting beyond the optimum planting window for a given environment (Coulter 2012, Nafziger 2008). In South Africa, early planting usually commences around October/November, though optimal planting window occurs in late spring/early summer (November/December) while planting can be extended to January. The current drastic variability in weather conditions might cause a shift in optimal planting date window, thereby leading to delay in planting date. The number of suitable days can vary greatly from year to year.

Rainfall patterns and other weather conditions associated with different planting dates have a modifying effect on length of the growing season, maize development and harvesting period (Beiragi et al., 2011). Maize yield response to planting date is very similar in different years and locations attributing yield benefits to early planting (Good et al., 2015, Nafziger 2008). Furthermore, maize hybrids respond differently to planting dates (Darby & Lauer 2002). Each maize hybrid has an optimum planting date and any deviation may negatively influence the growth duration and maize yield (Sárvári & Futó 2000). However, the number of growing degree days (GDD) needed for maize hybrids to reach various developmental stages is fairly uniform across environments (Hoegemeyer 2013).

Maize SC701 cultivar is one of the commonly grown hybrids in southern African. The desired traits of the cultivar include large ear size, long shelf life high yield and moderate drought tolerance (ARC 2014). It is a late maturing cultivar which requires an average of 1028 GDD from emergence (V_E) to physiological maturity (R_6) and an average of 6.4 mm/day of water from 12 leaf stage to full dent stage (Darby and Lauer 2002). The relationship between the maturity length of a maize hybrid and its GDD accumulations at a given location determine their optimal harvesting period and its adaptability. Intensive studies have shown the effect of maturity stages at harvest on maize yield and agreed that optimum time to harvest maize is when close to its physiological maturity (Daynard 1972, Henning et al., 2011, Jacob Junior et al., 2014). However, consideration was not given to its response under extreme or adverse weather conditions, which might prevent the crop from attaining physiological maturity. Nielsen (Bob) (2013) reported that approximate yield losses due to adverse condition on the field range from 50%, 39%, and 12% when harvesting occurs at R_4 (dough), R_5 (full dent), and half-milk line stages of kernel development respectively.

The relationship between the time of planting and harvest stages might bring possibility of higher yield during extreme temperature and rainfall. Since, maize growth and development varies with ambient temperature from emergence to physiological maturity. Anwar et al., (2015) explained that extreme temperatures cause developmental shift and disrupt reproduction processes. In addition, late-planted maize might experience cooler conditions during its early vegetative growth stages and extended towards grain filling stage, which may lengthen the grain filling period, if water stress is severe, kernel may store relatively lesser sugar, resulting in lower kernels weight and yields.

The relationships between seed harvested early before reaching physiological maturity and planting date need to be considered to prevent total yield loss under adverse weather

conditions. Since future weather conditions are not easy to predict, management strategies to improve yield of early harvested maize are required to enhance production efficiency of maize farmers. Understanding the environmental and agronomic responses of maize hybrids would help to develop appropriate mitigation measures during adverse weather conditions.

The specific importance of planting dates and maturity stage at harvesting of SC701 cultivar are limited. Therefore, this research is given by the need to substantially increase the efficiency of maize production during adverse weather conditions. Hence, this study was conducted to evaluate the combine effect of planting dates and harvesting stages on yield of SC701 maize cultivar. It compares the efficiency of maize harvested at different maturity stage under different planting dates.

Materials & methods

The experimental site is the same as described in chapter 2, materials and methods section

Table 3.1: Physicochemical properties of soil at (0 - 20 cm) before setting up the experiments at Ukulinga site in 2014/15 and 2015/16 planting seasons

	Density (mg/L)	P (mg/L)	K (mg/L)	N (%)	Ca (mg/L)	pH (KCl)	Mg (mg/L)	Mn (mg/L)	Cu (mg/L)	Exch. Acidity (C mol /L)	Total cations (C mol/L)	Clay (%)	*Soil texture	Organic Carbon (%)
(1st season)	1.18	38	424	0.23	1739	4.45	581	27	10.8	0.18	14.72	31	Clayey loam	2.30
(2nd season)	1.13	32	427	0.23	1851	4.80	683	29	8.2	0.11	16.20	31	Clayey loam	2.23

* USDA soil classification system, Exch.Acidity = exchangeable acidity

The experimental site description, crop management used was the same as described in chapter 2, materials and methods section except that only recommended fertilizer dosage was used. In addition, experimental design and layout section and data collection were similar as described in chapter 2, materials and methods except at data collection for yield and yield component.

Yield and yield components

A standardized maize developmental stage system was used to identify the harvesting stages (Ritchie et al., 1992). Maize ears were harvested at three stages of development, milk stage (R₃) which is 18 days after silking (DAS), dent stage (R₅) which is 42 DAS and physiological maturity (R₆) which is 58 DAS. At each harvest six ears were randomly selected in each plot and first ear from the top of the plant was harvested by hand.

The seed moisture content (SMC) was determined by wet weight basis and was calculated by as described by equation 3

$$SMC = \frac{M_1 - M_2}{M_1} \times 100$$

Where, M₁ is the mass in grams of the seeds before drying and M₂ is the mass in grams of dried seeds.

Thousand-seed weight (TSW) was determined by count hundred seed from each treatment and multiplying by 10. Harvested ears were placed on benches in the glasshouse under dry conditions and dried to < 12% moisture content. Yield components such as ear length (EL), ear diameter (ED), number of rows/ear (RN/E), kernel number/row (KN/R) and seed yield were recorded after drying the cobs from each harvesting stages. The length of ear was measured from the base to tip by using measuring ruler and mean of six ears were expressed in

cm. The weight (yield) of the individual ear after drying to uniform moisture content 12% was recorded and the mean of six ears was expressed in grams per ear and later calculated as kg/tons

The harvest index (HI) was computed as the ratio of seed yield to the total above ground as described in equation 4

$$HI = \text{Seed yield} / \text{biological yield} \times 100$$

The same procedure was followed in the second planting season. The total biomass (TB) and harvest index (HI) were determined at the end of physiological maturity in both seasons except in 2015/16 season where the dent stage of the maize was harvested and used for total biomass and harvest index under mid and late planting dates due to the invasion of wild pigs.

Description of statistical analysis

Bartlett's test was done to determine homogeneity of variances for all measured variables. Significant differences at 5% occurred in all data indicating common variance among the planting dates in each season. Hence, data for planting dates were pooled for subsequent analysis for crop phenology and yield components. The test did not show homogeneity of variances for crop growth and physiology across the seasons, thus combined analysis was not done. Data collected were analysed using split plot from GenStat® (Version 16, VSN International, UK) statistical package. Multiple comparison tests were done using Fisher's least significant difference (LSD) at the 5% level of significance.

Results

Weather conditions

The weather data showed differences in the rainfall and temperatures measured across the three planting dates in each season. The weather data for 2014/15 was consistent with the long-term weather data for Ukulinga site. However, weather data for 2015/16 deviated marginally with an average temperature increase of 2.3°C (November to March) from the observed annual mean maximum temperatures for the months. Comparing the two seasons, maximum and minimum temperatures were higher in 2015/16 (28.1°C and 15.6°C) than 2014/15 (24.9°C and 14.9°C respectively) which were not in conformity with the long-term maximum and minimum temperatures of 25.6°C and 16.9°C (Fig. 3.1). These might have led to higher heat unit accumulation during 2015/16 season especially at early (1479.6°cd) and mid (1480.7°cd) planting dates and decreased during the late (1213.1°cd) planting compared to 2014/15 season where there was increasing trend from early, mid and late planting dates (1289.4°cd, 1352.2°cd and 1831.84°cd respectively).

Comparing the rainfall received during the early, mid and late planting dates in the two seasons, 2014/15 season (407.9 mm, 371.6 mm and 267.2 mm) received more distribution of rain than 2015/16 (444.8 mm, 360.7 mm and 208.4 mm respectively) (Fig. 1). Almost 80% of rainfall received during 2015/16 was received from January-March while the rest were sparingly distributed. In addition, there were more days of no rainfall during the reproductive stage of the crops in 2015/16 than 2014/15 season (Fig. 3.1). The observed results indicated high accumulation of heat unit and occurrence of water stress, which hastened crop development and reduced the grain-filling period in 2015/16 than 2014/15. In addition, the weather data showed more favourable environmental conditions for the growth and development of maize in 2014/15 than 2015/16 though there were more occurrences of hail storms during the late vegetative stage of early planting dates in 2014/15 than 2015/16 which substantially reduced the plant leaf area and lead to yield loss in both seasons.

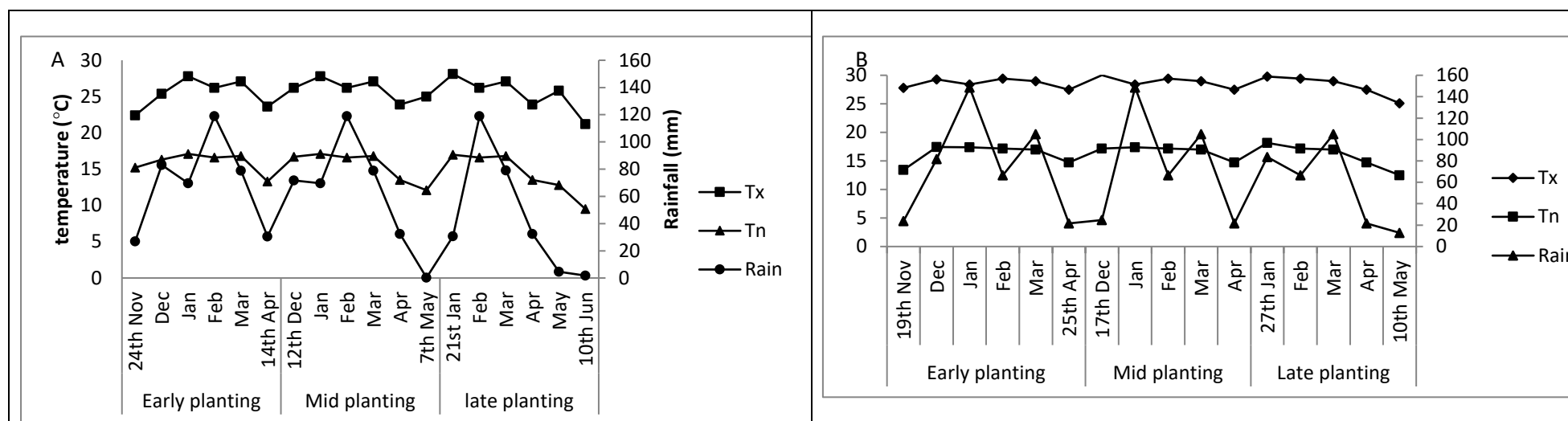


Fig 3.1: Variation in monthly rainfall (rain) and maximum (Tx) and minimum (Tn) temperatures (°C) recorded under different planting dates during A = 2014/15 and B = 2015/16 planting seasons at Ukulinga, Pietermaritzburg South Africa.

Crop phenology

The time to reach 50% tasselling and silking were shown to be significantly affected by seasons and planting dates (Table 3.2). Time to reach 50% tasselling and silking showed significant differences ($P < 0.05$) among the planting dates. Time to reach 50% tasselling and silking were statistically similar in early (873.8 °cd, 949.6 °cd) and mid planting dates (873.9 °cd, 937.4 °cd) but were shortened in late planting (835.1 °cd, 898.7 °cd) during 2014/15 season. Differences in phenological stages were more distinct in plants from 2015/16 season where early planting (892.8 °cd, 980.3 °cd) had prolonged time in reaching tasselling and silking followed by plant from mid-planting (843.8 °cd, 904.1 °cd). However, late planting (736.2 °cd, 883.6 °cd) had the shortest time to reach tasselling and silking (Table 3.2).

Table 3.2: Phenological stages in SC701 maize at different planting dates during the 2014/15 and 2015/16 seasons. Values in the same column sharing the same superscript letter are not significantly different ($P < 0.05$)

Seasons	Planting dates	TTT (°cd)	TTS (°cd)
2014/15	Early	873.80bc	949.60b
	Mid	873.90bc	937.40b
	Late	835.10b	898.70a
2015/16	Early	892.80c	980.30a
	Mid	843.80bc	904.10b
	Late	736.20a	883.60a
LSD _(P<0.05) Seasons		13.250	4.510
LSD _(P<0.05) Planting dates		22.860	4.860
LSD(P<0.05) Seasons × Planting dates		27.440	6.270

*TTT and TTS = time to reach 50% tasselling and silking respectively

Crop growth and physiology

The interaction of planting date and days after planting were not significantly different ($P > 0.05$) for plant heights during 2014/15. However, significant differences ($P < 0.05$) were observed in their interaction for leaf numbers. During 2015/16, plant heights showed significant differences ($P < 0.05$) for interaction of planting date and days after planting (Fig. 3.2). Plant heights were lower during 2015/16 compared to 2014/15 and were more affected by the erratic rainfall during 2015/16 season.

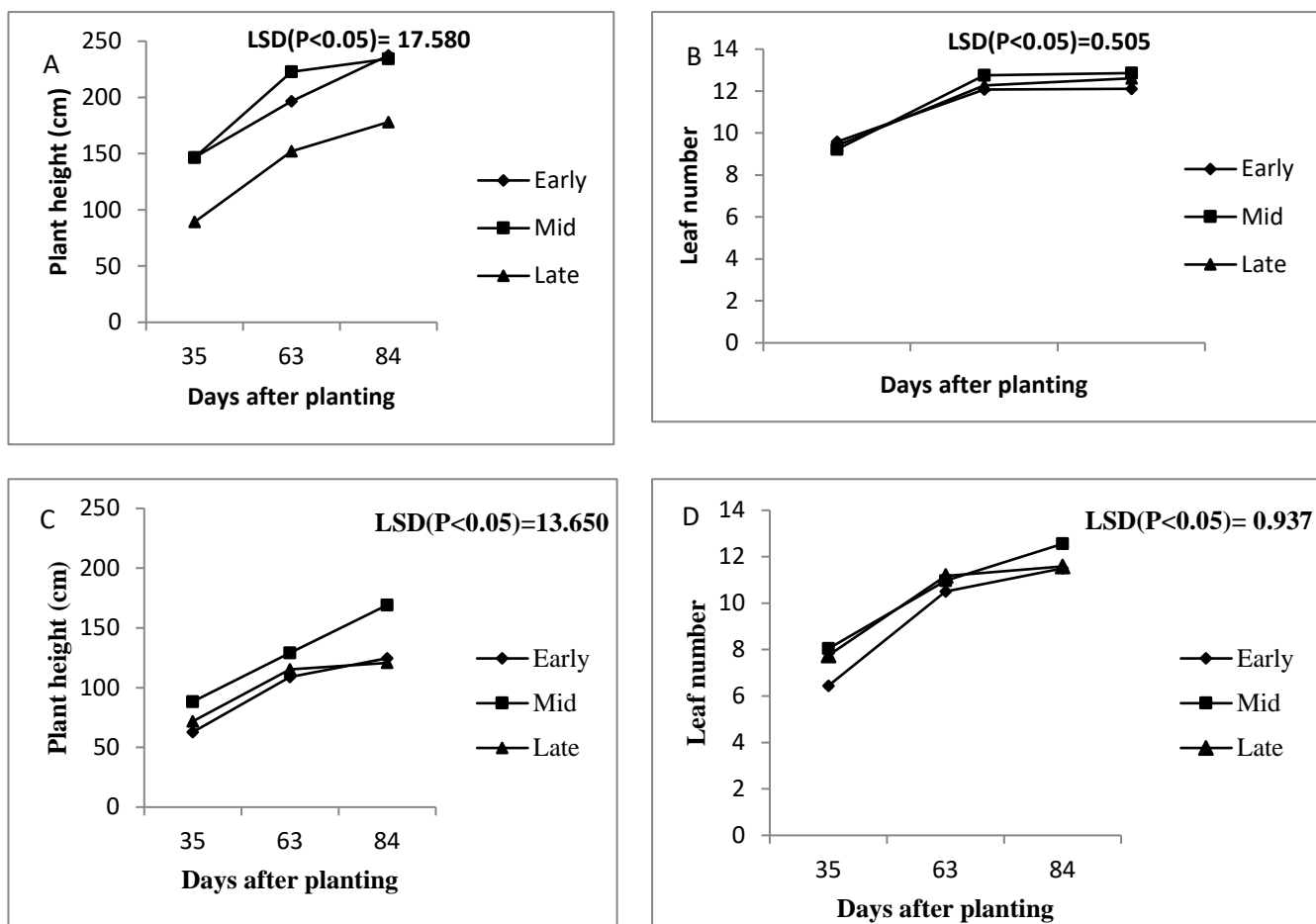


Figure 3.2: Plant height and leaf number of SC701 maize under different planting dates during (A and B) 2014/15 and (C and D) 2015/16 planting seasons. Early, mid and late represent early planting, mid planting and late planting.

The interaction of planting dates and time after silking (which was recorded as days after silking) were strongly influenced ($P < 0.001$) by plant chlorophyll content index (CCI) in each planting seasons (Fig. 3.3). During 2014/15, there were significant differences ($P < 0.05$) in the interactions of planting dates and days after silking for CCI. It decreased linearly from seven to 58 days after silking. In addition, early planting had the highest (48.90) CCI relative to mid (42.40) and late planting (42.60). The CCI followed similar trends in each planting date. During 2015/16, plants CCI under early planting dates were significantly higher (49.51) relative to mid (43.82) and late planting (43.00). The CCI decreased from seven days after silking, then increased across 32 days after silking and later declined at 58 days after silking across the planting dates. There was no distinct trend in the measured CCI across days after silking; this might be due to inconsistent distribution of precipitation (weather data).

The interaction of planting dates and days after silking were significantly ($P < 0.001$) influenced by stomatal conductance (gs) during 2014/15 (Fig. 3.3). Stomatal conductance (gs) was lower under late planting relative to early planting conditions (Fig. 3.3). The results showed decreasing trends for gs across days after silking. Mid planting > early planting > late planting. During 2015/16, the interaction of planting date and days after silking (DAS) significantly ($P < 0.05$) influenced gs. Mid planting gave the highest gs among the planting dates from 18 DAS and decreased to 58 DAS. During both planting seasons, measurements of stomatal conductance were typically recorded during the reproductive stages of the crops.

There were highly significant interactions ($P < 0.001$) among the planting dates and days after silking at both seasons with respect to LAI (Fig. 3.3). During 2014/15 season, they were consistent with observations of plant height and leaf number across days after planting. Over time, plants from mid planting date had higher leaf area index than plants from early planting which might be due to occurrences of hailstorm at later vegetative stage of the crop in

early planting. Comparing the plant LAI obtained from the three planting dates, leaf area index increased from 7 DAS to 18 DAS and then decrease from 32 DAS to 58 DAS (Fig 3.3). During 2015/16, plants from mid planting date had higher LAI across days after silking, while the least was recorded in plants from late planting date.

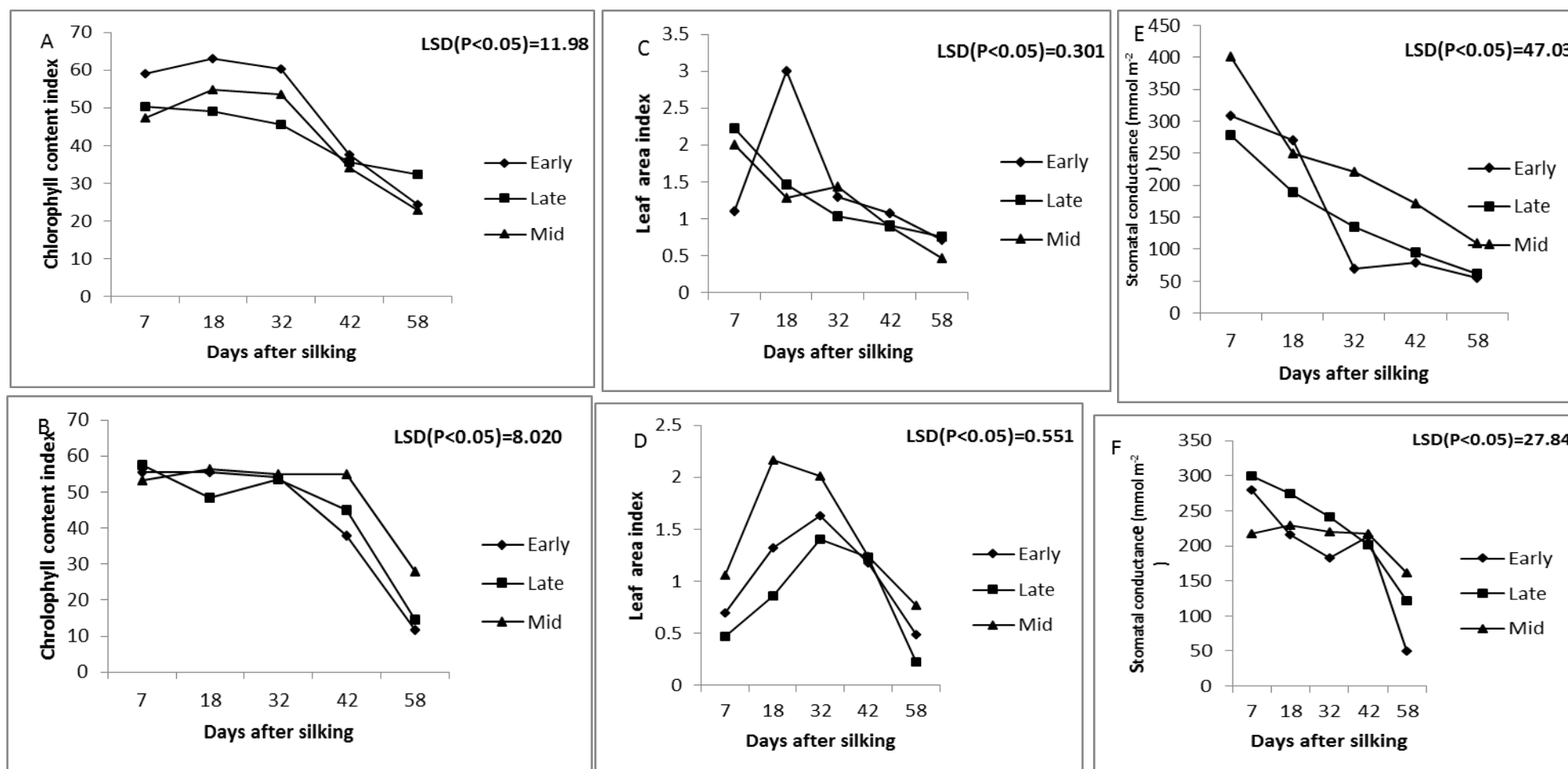


Fig 3.3: Chlorophyll content index, leaf area index and stomatal conductance of SC701 maize grown under early, mid and late planting dates during the (A, C and E) 2014/15 and (B, D and F) 2015/16 planting seasons.

Yield and yield components

The total biomass and harvest index were significantly ($P < 0.05$) influenced by the planting date during 2014/15. There were no statistical differences in mean values for biomass and harvest index under early and mid-planting dates (Fig. 3.4). The harvest index and total biomass obtained in 2015/16 was significantly influenced ($P < 0.001$) by the planting date. Total biomass and harvest index were significantly ($P < 0.05$) higher (37.5% and 22% respectively) during 2014/15 in comparison to 2015/16. The total biomass and harvest index of maize obtained from early and mid-planting were similar in 2014/15 season. While, plants from late planting had the least biomass and harvest index. Overall, there were significant differences ($P < 0.05$) among planting dates, seasons and their interactions for harvest index and highly significant difference ($P < 0.001$) occurred for total biomass (Fig.3.4). Total biomass and harvest index obtained in both seasons followed the observed growth patterns within each planting date.

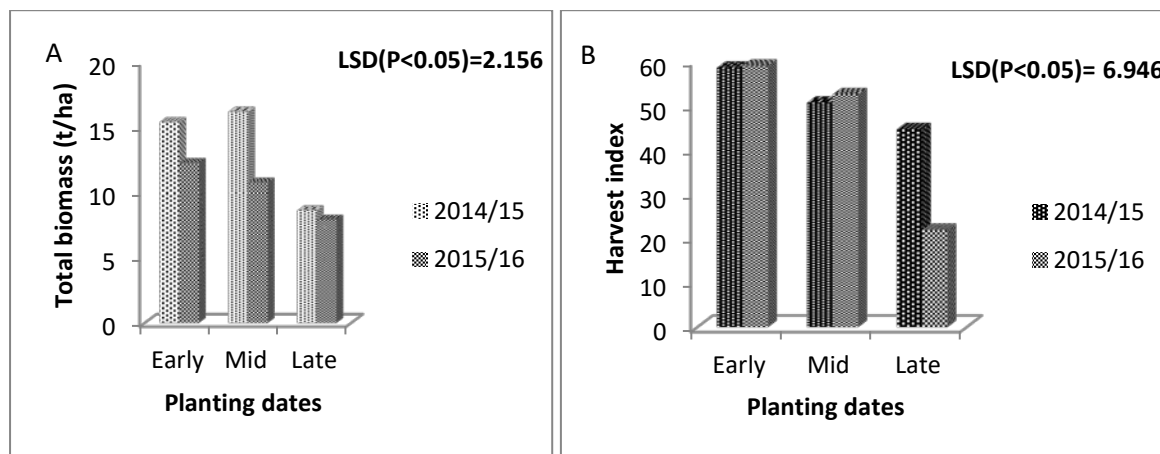


Fig 3.4: A=Total biomass of SC701 maize harvested at physiological maturity under early, mid and late planting during 2014/15 and 2015/16 planting season and B = harvest index of SC701 maize at early, mid and late planting during 2014/15 and 2015/16 planting season

Results of yield components (grain yield, thousand seed weight, ear length, ear diameter, kernel number/row, row number/ear and seed moisture content) over the two planting seasons (2014/15 and 2015/16) showed much variability between seasons, harvesting stages and planting dates (Table 3.3). During 2014/15, grain yield and thousand seed weight were significantly influenced ($P < 0.001$) by the interactions of planting date \times harvesting stage. Ear length and KN/R were significantly influenced ($P < 0.05$) by the interaction (Table 3.3). During 2015/16 season, the interactions of planting dates \times harvesting stages had strong effect ($P < 0.05$) on ear diameter, KN/R, thousand seed weight and grain yield. This interaction significantly influenced ($P < 0.001$) seed moisture content. However, the interaction had no significant influence on kernel number/row, kernel row /ear (Table 3.3). The observed weather data for 2015/16 season showed lesser distribution and lower-than-average rainfall and higher atmospheric temperature.

During 2014/15, the maize ear length and thousand seed weight obtained at physiological maturity under early and mid-planting dates were statistically similar. Ear length obtained at dent stage under early planting was (21%) higher than those from physiological maturity under late planting. During 2015/16, the ear diameter and thousand seed weight harvested under mid planting were higher than those harvested at physiological maturity under late planting. Also, similarity was observed in thousand seed weight and yield obtained at dent stage and physiological maturity under mid planting which was higher than those obtained under late planting.

Over all, planting dates significantly influenced ($P < 0.001$) ear length, thousand seed weight and had significant effect ($P < 0.05$) on ear diameter and kernel row/ear. The harvesting stages had significant effect ($P < 0.001$) on the yield components except the kernel number/row and kernel row/ear. The interactions of planting dates \times harvesting stages have significant

effect ($P < 0.05$) on ear length, thousand seed weight, seed moisture content and significantly influenced ($P < 0.001$) the grain yield (Table 3.3). The interactions of planting dates \times harvesting stages \times years significantly influenced ($P < 0.05$) the ear diameter, thousand seed weight and yield (Table 3). All the yield components obtained in 2014/15 were higher compared to 2015/16 season harvest.

Table 3.3: Yield and yield components of SC701 maize under different planting dates and harvesting stages during the 2014/15 (1st year) and 2015/16 (2nd year) seasons. Values in the same column sharing the same superscript letter are not significantly different ($P > 0.05$).

EL= ear length, ED = ear diameter, HS = harvesting stages, PH = physiological maturity, TPP = Treatments Planting dates, TSW= thousand seed weight, Y= yield, KN/R

TPP	HS	EL (cm)		ED (cm)		TSW (g)		Y (t/ha)		KN/R		KR/E		MC	
		1 st year	2 nd year	1 st year	2 nd year	1 st year	2 nd year	1 st year	2 nd year	1 st year	2 nd year	1 st year	2 nd year	1 st year	2 nd year
Early	Milk stage	28.80cd	25.00b	7.69a	7.88cd	269.20a	331.50a	2.19b	2.44ab	50.00b	33.75b	13.00a	12.50a	77.00d	80.10d
Mid		24.52b	22.00b	7.50a	7.56abc	270.20a	430.00b	1.97a	2.67b	50.50b	38.87b	13.00a	13.00a	71.59d	77.39d
Late		23.10ab	19.12a	6.81a	7.00a	238.90a	364.50a	2.26b	1.93a	46.00a	30.37ab	13.08a	12.25a	81.70e	80.10d
Early	Dent stage	29.75d	23.50	8.63a	7.06ab	611.50c	603.50d	3.88c	4.27d	51.00b	34.75b	12.50a	12.00a	48.59bc	59.12c
Mid		27.58c	22.62b	8.24a	8.13cd	670.40d	697.80e	4.61c	5.12e	50.50b	38.67b	12.42a	12.75a	42.19b	48.33b
Late		22.75a	16.50a	7.56a	7.50abc	414.50b	512.20c	2.26b	2.55ab	40.00a	27.00a	12.75a	12.37a	56.92c	54.34c
Early	PM	29.00cd	19.50a	8.81a	8.50d	698.40d	766.50f	6.01d	4.96e	51.12b	28.25a	13.38a	12.08a	29.76a	32.64b
Mid		28.50cd	17.94a	8.50a	8.65d	686.40d	756.80e	5.83d	5.28e	49.75ab	33.12b	12.17a	12.71a	24.17a	24.18a
Late		23.40ab	13.44a	7.44	7.87bcd	408.50b	610.20d	3.94c	3.77c	41.75a	23.03a	12.88a	12.15a	36.69b	24.66a
		($P < 0.05$)	($P < 0.05$)	($P > 0.05$)	($P < 0.05$)	($P < 0.001$)	($P < 0.05$)	($P < 0.001$)	($P < 0.05$)	($P < 0.05$)	($P < 0.05$)	($P > 0.05$)	($P > 0.05$)	($P < 0.05$)	($P < 0.001$)
Lsd value		1.714	2.825	0.613	0.815	58.220	75.06	1.004	0.680	4.472	8.390	1.196	1.205	6.701	5.490
PD ¹		(P < 0.001)		(P < 0.05)		(P < 0.001)		(P < 0.001)		(P > 0.05)		(P < 0.05)		(P > 0.05)	
Lsd value		0.766		0.410		33.010		0.305		4.298		0.482		3.911	
H ¹		(P < 0.001)		(P < 0.001)		(P < 0.001)		(P < 0.001)		(P > 0.05)		(P > 0.05)		(P < 0.001)	
		1.195		0.410		29.76		0.305		2.601		0.574		3.139	
Year ¹		(P < 0.001)		(P > 0.05)		(P < 0.001)		(P < 0.001)		(P < 0.001)		(P > 0.05)		(P < 0.001)	
Lsd value		0.926		0.240		21.310		0.279		2.367		0.384		1.900	
P × H ¹		(P < 0.05)		(P > 0.05)		(P < 0.05)		(P < 0.001)		(P > 0.05)		(P > 0.05)		(P < 0.05)	
Lsd value		1.919		0.508		23.520		0.742		5.212		0.896		5.488	
P × H × Y ¹		(P > 0.05)		(P < 0.05)		(P < 0.05)		(P < 0.05)		(P > 0.05)		(P > 0.05)		(P > 0.05)	
Lsd value		2.264		0.658		65.480		0.923		7.005		1.178		6.632	

=kernel number/row, KR/E = kernel row number/ear, MC = seed moisture content and 1 = Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons for the three planting dates. Mean separation was performed using the LSD value for the planting date, harvesting stages and year interaction

Discussion

Weather conditions optimal for production of maize are likely to be less predictable in future due to variability in weather conditions and may have resultant effect on harvesting stages (Blignaut et al., 2009). Recent findings indicated the need for long-term adaptation strategies to ensure food security in response to climate change (Ziervogel et al. 2014). These findings purposely focused on a maize SC701 cultivar that is widely grown across all levels of agricultural systems in southern Africa, from subsistence to small-scale and industrial agriculture.

This current study showed that increase in atmospheric temperature and below average rainfall experienced made 2015/16 a drier season compared to 2014/15 season. This might have caused stress in the plant growths and metabolic activities. Early and mid-planting had averagely warm temperature and rainfall necessary for optimal growth and development while drop in temperature and rainfall during the late planting resulted in deficit GDD which hastened flowering in late planting at both seasons. This might have caused reduction in partitioning of assimilates during grain filling and led to a decline in yield and yield components across seasons. In addition, the observed association of leaf physiological parameters (CCI and g_s) are related with photosynthetic potential of the plants. Early planting in 2014/15 and mid planting in 2015/16 seasons experienced sufficient distribution of rainfall largely in their growth and developmental stages, which enhanced stomatal conductivity. Manzoni et al., (2011) reported that high stomatal conductivity increased CO_2 diffusion inside the leaf thus improving photosynthetic rate. Low stomatal conductivity in late planting at both seasons might be due to stomatal closure, which is widely thought to be plant's first line of defence in response to developing water stress. High stomatal conductance and chlorophyll content index in plants under early and mid-planting increased the photosynthetic capacity, indicating that the plants have higher capacity to allocate more assimilates to developing kernels. Decrease in chlorophyll contents under extreme weather conditions were consistent with Anjum et al., (2011) findings who reported reduced chlorophyll contents under progressive drought stress in maize, although they did not focus on plant chlorophyll contents under different planting dates.

The differences in planting dates led to variation in canopy stature. On average, early and mid-planted maize had similar performances, having taller plants, greater leaf number and LAI relative to late-planted maize. Thus, producing large canopy earlier in the seasons, which optimally utilized solar radiation for photosynthesis. The lower plant growth under late planted maize across DAP might have been due to limited water availability for plant use under extreme weather conditions which reduced photosynthetic rate, CO₂ assimilation and fixation. Similar findings showing reduction in plant height, leaf number and LAI in maize have been reported in literature (Anjum, et al. 2011, Blum 2005, Tardieu 2014). This implied that as the planting date of maize is delayed the probability of having high canopy stature would be reduced in any planting season.

Planting in different environmental conditions influenced the phenological stages of maize. The results of crop phenology showed clear response to differences in rainfall distribution and temperature received at each planting date and season. The accumulated heat units for tasselling and silking were higher under optimal temperature (early and mid-planting) which might be due to sufficient availability rainfall for plant use but was shortened under extreme weather conditions (late planting). Thereby, causing late-planted maize to flower earlier because of deficit in accumulated heat units as compared to early and mid-planted plants. Parthasarathi et al., (2013) reported similar findings that low heat unit's accumulation at the time of flowering lead to early flowering in cereals. In addition, Hatfield et al., (2015) explained that limited water availability to plant during flowering had an adverse effect on its physiological status causing decline in photosynthetic rates and plant growth. This current study observed that late-planted maize had the lowest grain yield.

Results of total biomass and harvest index obtained in both seasons showed similarities between early and mid-planting while lower trends were observed under late planting dates which were consistent with the trend observed for stomatal conductance, chlorophyll content and plant growth parameters. This explained the reason why researchers have previously ascribed biomass accumulation to source strength

and sink's capacity, which are enormously reduced by limited soil water (Aslam et al., 2015, Gambín et al., 2006).

The yield components affected by the interaction of maturity stage at harvest and planting date were grain yield, ear length, ear diameter and thousand seed weight. The high performance of ear length, ear diameter and thousand seed weight obtained at dent stage (42 DAS) might be due to moderate and favourable weather conditions experienced. A stressful environment during grain filling could have caused the reduction in thousand seed weight, which would have influenced the ear diameter. The canopy stature determined the rate of light interception received at each planting date, which greatly influenced the plant source-sink relationship and thus seed weight (Gambín, et al. 2006, Novacek et al., 2013). This implied that seed weight of kernel harvested relatively to physiological maturity (42 DAS) under favourable growing condition would be heavier than its counterpart seeds at physiological maturity under extreme weather conditions.

Planting date and maturity stage at harvest have strong effect on grain yield. However, similarity in grain yield was observed in seeds from dent stage and physiologically mature seeds under mid planting date (moderately favourable weather conditions). This might be due to decline in the rate of remobilization of photosynthetic assimilate to the kernel as it tends toward physiological maturity. Given the possibility of obtaining reasonable yield when harvesting commence at dent stage.

Harvesting too early at milk stage (18 DAS) due to prevailing extreme weather conditions should not be encouraged because it led to highest yield loss because of low nutrients accumulation as expressed in low thousand seed weight and grain yield except if it meant for silage production. The continuous decrease in the seed moisture content from milk stage to physiological maturity indicated increase in biomass accumulation towards later stage of maturity (Aslam, et al. 2015). Planting date had greater effect on seed moisture content in the drier season and late planting date than in warm season under early and mid-planting date. This effect could be due to increase the atmospheric temperature in drier season, which hastened reduction in the seed moisture content. Planting dates and stages of harvesting did not

affect kernel number/row and kernel row/ear. This could be attributed to their strong dependence on their genetics make up and could be only hindered by severe environmental stresses. This current research agreed with Modi & Greenfield (2010) who reported that reduction in grain yield experienced with extreme weather conditions was due to an increase in the duration of the grain-filling and decrease in the rate of grain filling which were insufficient to prevent grain yield loss. In addition, Hasanuzzaman et al., (2013) reported that accumulated high temperatures caused an array of morphological, physiological and biochemical changes within plant such as decrease in the number of grains and kernel weight. The improvement in grain yield of the early and mid-planted maize might be due to the increase in plant growth under adequate soil moisture which enabled it to reach post-anthesis stage during the hottest summer periods and escaped greater water deficit stress compared with later planted maize where nutrient availability, uptake, transport and grain filling coincided with extreme temperatures and water deficit.

Conclusions

Low rainfall distribution and extreme temperatures cannot be predicted in any specific season or stage of plant growth and development. Evaluating the response of maize to a changing climate can provide viable options for enhancing adaptive capacity of smallholder farmers in these areas. This current finding showed that the risk of yield losses due to adverse weather conditions decrease as maize nears physiological maturity. The weather conditions at each planting date and stage of maturity at harvest have considerable effect on the rate of grain filling and yield. Maize seed harvested earlier (late dent stage) under moderately favourable growing conditions out performed its counterpart that could reach physiological maturity under extreme weather conditions. In addition, there is high risk that maize plant would not be able to reach physiological maturity with delayed planting or under adverse weather conditions. Planting date affects plant growth, development and yield depending on environmental conditions and stages of maturity at harvest.

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CHAPTER 4

Soil fertility and maturity effect on maize yield under dry land farming condition¹

¹In preparation for journal of soil science and plant nutrition

Abstracts

Low maize productivity among smallholder farmers who cultivate under rain fed conditions could be improved with adjustment in management practices. Understanding critical need during seed development would help farmer weigh crop management options as climate patterns change. This study aimed to determine the interactive effect of soil fertility and maturity stage on maize yield. Maize cultivar of SC701 was harvested at milk (R_3), dent (R_5) and physiological maturity (R_6) stages from two field trials during 2014/2015 and 2015/16 summer seasons. The experimental design was split plot design with fertility level (main factor) and maturity stage (sub plots) replicated ($\times 4$). Response of maize to fertility levels and maturity stages was determined by variables of plant physiological growth and yield parameters. The plant growth and physiological parameters measured were significantly influenced ($P < 0.001$) by the interaction of fertility levels and days after planting and silking in both seasons. The interactions of fertility levels and maturity stages significantly influenced ($P < 0.05$) all the yield components during 2014/15 (warmer) season, as well as seed yield, harvest index, thousand seed weight and total biomass in 2015/16 (drier) season. The 2015/16 was drier than 2014/15 season, which resulted in lower seed yield and yield components. Optimal fertilization improved maize yield at each stage of maturity. This study showed that harvesting stress-free optimally fertilized maize at dent stage maximize the yield potential of the crop and will be the best option than expose the maize to reach physiological maturity under stressful conditions.

Keywords: Fertilizer, Growth, Maize, Maturation, Production

Introduction

Improving maize (*Zea mays* L.) yield has become a major goal of most developing countries, because maize is a major staple food crop in the world. Its production has been predicted that it would surpass both wheat and rice and become the number one staple crop globally by 2020 (Von Bormann and Gulati, 2014). However, low productivity among rain fed smallholder farmers' limits this goal.

One of the commonly grown maize hybrid by farmers in southern Africa is SC701 cultivar, which is a late maturity, crop taking up to 135days for its vegetative and reproductive development. However, the soil and crop are exposed to variable weather conditions during their development prompting the farmers to determine management strategies that could be employed pre-season and mid-season to overcome these challenges.

Optimal management practices such as improving soil fertility and monitoring the stages of maturity of maize with environmental changes especially during seed production may be imperative for boosting the growth and production of maize. There is therefore need to develop new strategies to enhance these management practices in maize crop production. Considerable work has been reported on response of maize yield to different harvesting stages and fertilizer application (Aboutalebian et al., 2012, Demir et al., 2008). However, efforts are still needed concerning the interactive effect of these management factors to meet up with SDGs (2015) goals of doubling crop productivity by 2030 among small-scale farmers.

Most soils in Sub-Sahara Africa are deficient in soil nutrients for nitrogen (N), phosphorus (P) and potassium (K) due to continuous cultivation, which has serious consequence on yield (Sommer et al., 2013). Body of knowledge obtained from DAFF (2013) indicated that 12% of South Africa land are suitable for dry land production with only 3% considered truly fertile land. Majority of these soils are low in organic matter. Hence, decline in the amount of rainfall distribution could worsen the situation.

Nevertheless, the soil fertility status may influence maturity stage and attainment of maximum dry weight before or at physiological maturity.

Nature (2012) reported that inorganic fertilizers are the best way to feed Africa in the short term. Application of K and P fertilizer to soil with medium levels of the nutrient enhanced maize maturity by allowing translocation of sugar to the ear and increase grain development (Armstrong, 1998). While, nitrogen fertilization delays leaf senescence, maintains higher photosynthetic rate, and provides carbohydrates for grain filling thereby enhancing crop maturation and seed yield. Therefore, application of fertilizers can hasten seed development, which will help harvesting before adverse weather conditions set in.

Improving soil fertility through fertilization has been reported by several authors to influence seed maturation and yield through improved soil physical and chemical resilience to climate variation (Blair et al 2006). Gupta, (2003) reported that grain filling stages in maize are influenced by soil fertility in that adequate application of phosphorus stimulates root development, hastened flowering and maturity in crops. During seed maturation processes, drop in rainfall or extreme high temperature might reduce the rate and duration of grain-filling leading to yield loss. Hence, maize seed producers are faced with the daunting task of either losing the entire crop or harvesting early to maximize seed production. Understanding the effect of soil fertility on seed maturation in relation to biomass accumulation and yield might be of great help in providing beneficial information for manipulating source-sink relationship and improve maize yield.

Therefore, this study aimed to determine the effect of different maturity stages and soil fertility level on SC701maize yield. The study hypothesized that optimal soil fertility level would enhance the seed yield harvested early before attainment of physiological maturity.

Materials and Methods

Site Description

Field experiments were conducted on chromic luvisols soil type, which was low in organic carbon, available nitrogen and phosphorus at two sites for two consecutively summer 2014/2015 and 2015/2016 seasons. The experiments sites were situated at the University of KwaZulu-Natal's Ukulinga Research Farm (29°37'S; 30°16'E; 775 m a.s.l.) and Baynesfield site (29°75'S; 30°30'E; 850 m a.s.l.). Ukulinga Research Farm is classified as semi-arid with annual rainfall ranging from 644 - 838 mm with almost 80% occurring around October to April and mean annual temperatures of 18.4°C. Baynesfield is classified as humid climatic zone with an annual rainfall ranging from 800- 1280 mm and mean annual temperatures of 17°C, summer experience heavy mist with light to severe frost and hail occur in winter (Smith 2006). Soil texture at both sites was clay-loam though Baynesfield had higher clay percentage than Ukulinga site (Table 3.1). Conventional tillage system was practiced at both sites except during 2015/2016 season where conservative tillage was adopted at Baynesfield site. Foundation seed of SC701 maize hybrid of uniform size obtained from McDonalds seed company in KwaZulu-Natal, South Africa. It was planted during 2014/2015 season while its progeny was planted during 2015/2016 season. This was done to eliminate any environmental effect on the plant and to know parental history of the cultivar.

Crop management

The trials were planted at the onset of the rainy season in both seasons (23th and 24th November 2014/15 and 19th and 20th November 2015/16 season) for Baynesfield and Ukulinga sites respectively. Prior to planting, soil sampling was collected from top soil (0-20 cm) randomly and analysed for selected physicochemical properties. Based on soil fertility results (Table 3.1), fertilizer treatment consisted of N and P since the soil was not deficient of K. Control (no fertilizer application, 0: 0 kg/ha), minimal (application of half recommended fertilizer quantity, 100: 10 kg/ha) and Optimal (application of the recommended fertilizer quantity, 200: 20 kg/ha) for urea (N) and triple super phosphate granule fertilizer

(50% P), respectively. For N fertilizer, each level was split into two equal parts (half was applied at planting and other half at 8 weeks after planting). Weeding was done by hand hoeing once at Baynesfield according to Akinnuoye-Adelabu et al., (2017) and twice at Ukulinga due to its high weed bank. Pesticide was sprayed to control insect pest infestation.

Table 4.1: Physicochemical properties of soil at (0 - 20 cm) before setting up the experiments at Ukulinga and Baynesfield sites in 2014/2015 (1st year) and 2015/2016 (2nd year) planting seasons

Site	Density (mg/L)	P (mg/L)	K (mg/L)	N (%)	Ca (mg/L)	PH (KCl)	Mg (mg/L)	Mn (mg/L)	Cu (mg/L)	Exch. Acidity (C mol /L)	Total cations (C mol/L)	Clay (%)	*Soil texture	Organic Carbon (%)
Baynesfield													Clayey loam	3.40
(1 st season)	1.60	20	335	0.31	1511	5.45	373	19	4.8	0.14	11.61	43		
													Clayey loam	3.25
(2 nd season)	1.46	18	342	0.32	1582	5.62	371	20	4.6	0.13	12.35	42		
Ukulinga	1.18	38	424	0.23	1739	4.45	581	27	10.8	0.18	14.72	31	Clayey loam	2.30
(1 st season)														
(2 nd season)	1.13	32	427	0.23	1851	4.80	683	29	8.2	0.11	16.20	31	Clayey loam	2.23

Field Layout and Experimental Design

The experimental design was split-plot with sub-plots laid out in randomised complete blocks within the main plots and replicated four times. The main plot was 120 m² each comprising of the fertilizer levels [control (0:0), minimal (100:10 kg/ha) and optimal (200:20 kg/ha) of N and P fertilizer respectively]. The sub-plots (6 m²) consisted of harvesting stages [milk stage (R₃), dent stage (R₅) and physiological maturity (R₆)]. Planting spacing was 0.5 m x 0.75 m, translating to 26,667 plants/ha at each site. Two seeds per station were planted directly at a depth of 25 mm and later thinned to one seedling per station at four weeks after planting (WAP).

Data collection

Weather data

Daily weather data were obtained from an automatic weather station (AWS) Agricultural Research Council-Institute for Soil, Climate and Water (ARC-ISCW) network of automatic weather stations located within Ukulinga research farm and Baynesfield Estate. Weather parameters that were considered were rainfall (mm), maximum (T_{max}) and minimum (T_{min}) air temperature (°C).

Plant growth, physiological parameters and Yield and yield components were the same as described in chapter 2, materials and methods section.

Description of statistical analysis

A Bartlett's homogeneity of variances was carried out on the fertility levels and harvesting stages at both sites in each season. There were significant differences at 1% level for all the data from the sites. Hence, data from sites were pooled for subsequent analysis. Data collected were analysed using split plot from GenStat® (Version 16, VSN International, UK) statistical package. Multiple comparison tests were done using Fisher's least significant difference (LSD) at the 5% level of significance.

Results

Weather data

Weather data obtained for the two sites were in conformity with long-term weather data reported for Ukulinga and Baynesfield in section 2.1. Comparing the two planting (2014/15 and 2015/16) seasons, weather conditions at both sites were a bit similar in 2014/2015 season because plant growth and development occurred nearly at the same time (Fig.4.1). Also, maximum and minimum temperatures were relatively similar though, Baynesfield have higher T_{\max} and T_{\min} (26.9°C, 14.4°C) than Ukulinga (25.4°C and 15.9°C) in 2014/15 season respectively. Maximum and minimum temperatures were consistent with long-term temperature averages of 25.6 and 18 °C (Table 4.2). However, weather data for 2015/16 deviated marginally with an average temperature increase of 2.3°C (November to March) from the observed annual mean maximum temperatures for the months. Comparing the two seasons, maximum and minimum temperatures were higher in 2015/16 (28.1°C and 15.6°C) than 2014/15 (24.9°C and 14.9°C respectively) which were not in conformity with the long-term maximum and minimum temperatures. Rainfall received at both sites for both seasons up to each harvesting stages differed (Fig. 4.1). For example, (353.3 mm, 386.6 mm) (373.3 mm, 394.5 mm) and (407.8 mm, 475.0 mm) of rainfall were received up to the milk, dent and physiological maturity stage at Ukulinga and Baynesfield sites during 2014/15 season respectively. However, the rainfall distribution in 2015/16 was quite lower compared to those received in 2014/15 season at both sites. Almost 80% of rainfall received during 2015/16 was received from January-March while the rest were sparingly distributed. In addition, there were more days of no rainfall during the reproductive stage of the crops in 2015/16 than 2014/15 season (Fig 4.1). The results indicated high accumulation of heat unit and occurrence of water stress which hastened crop development and reduced the grain filling period in 2015/16 than 2014/15 seasons. However, Baynesfield had received higher rainfall than Ukulinga site in each season. The weather data

showed more favourable environmental conditions for the growth and development of maize in 2014/15 compared to 2015/16 season.

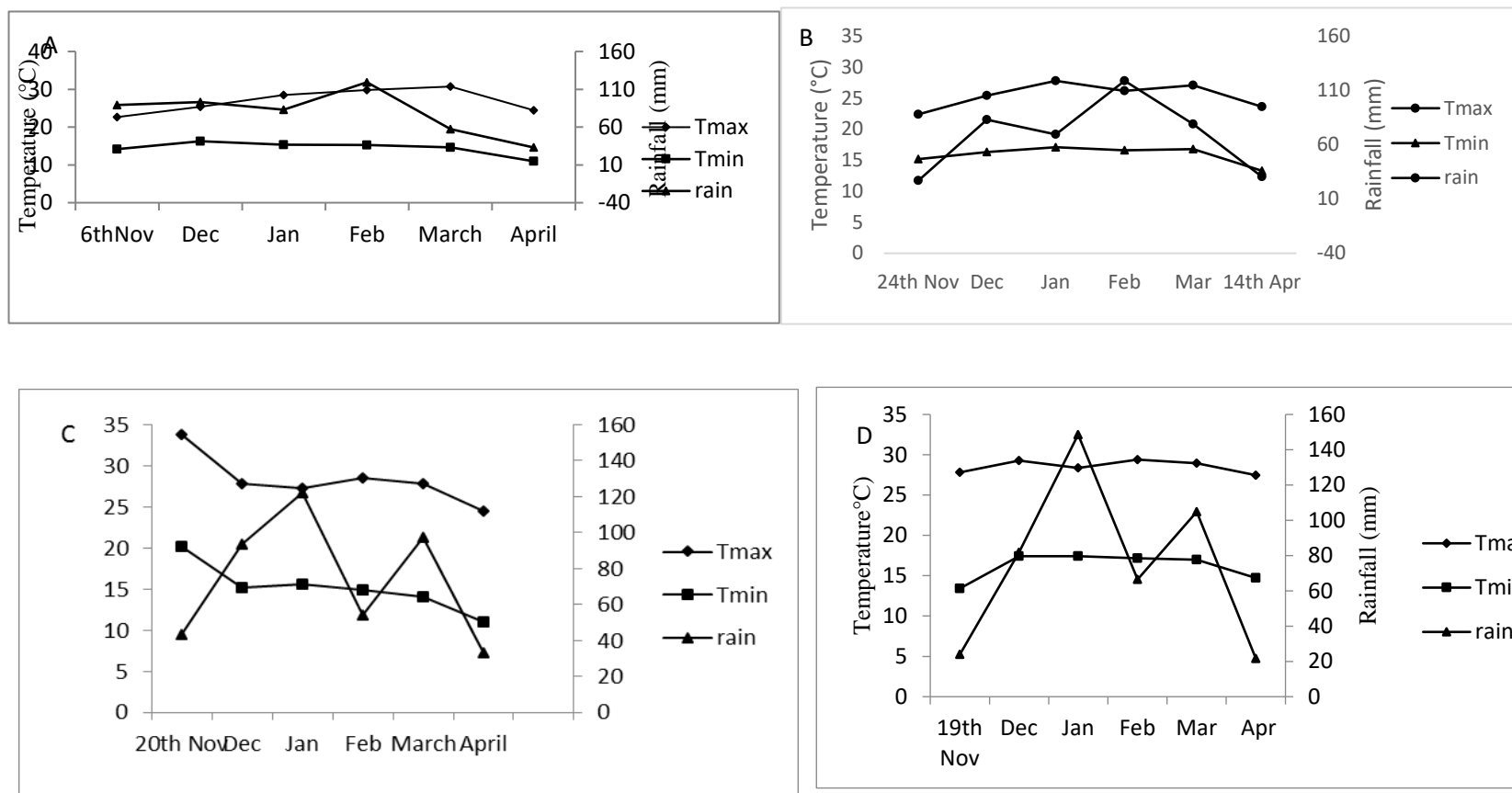


Figure 4.1: A and B = weather data during 2014/15, C and D = weather data during 2015/16 seasons for Baynesfield and Ukulinga sites respectively.

Crop growth and development

Plant height and leaf number recorded during 2014/15 season, showed highly significant differences ($P < 0.001$) among fertility levels and DAP. Significant interactions ($P < 0.05$) only existed between fertility level and site with regards to plant height (Fig 3.2 and 3.3).

During 2015/2016, ($P < 0.001$) highly significant differences in plant height and leaf number were recorded among fertility levels, sites and DAP. There were significant interactions for leaf number among fertility levels, but no significant interaction was observed for plant height among fertility levels, except at site and DAP. Plant height was significantly lower during 2015/2016 compared with 2014/2015 season. Likewise, in no fertilizer application trial compared to minimal and optimally fertilizer trials. Plant height and leaf number were affected by the occurrences of drought during 2015/16 compared to 2014/15 season.

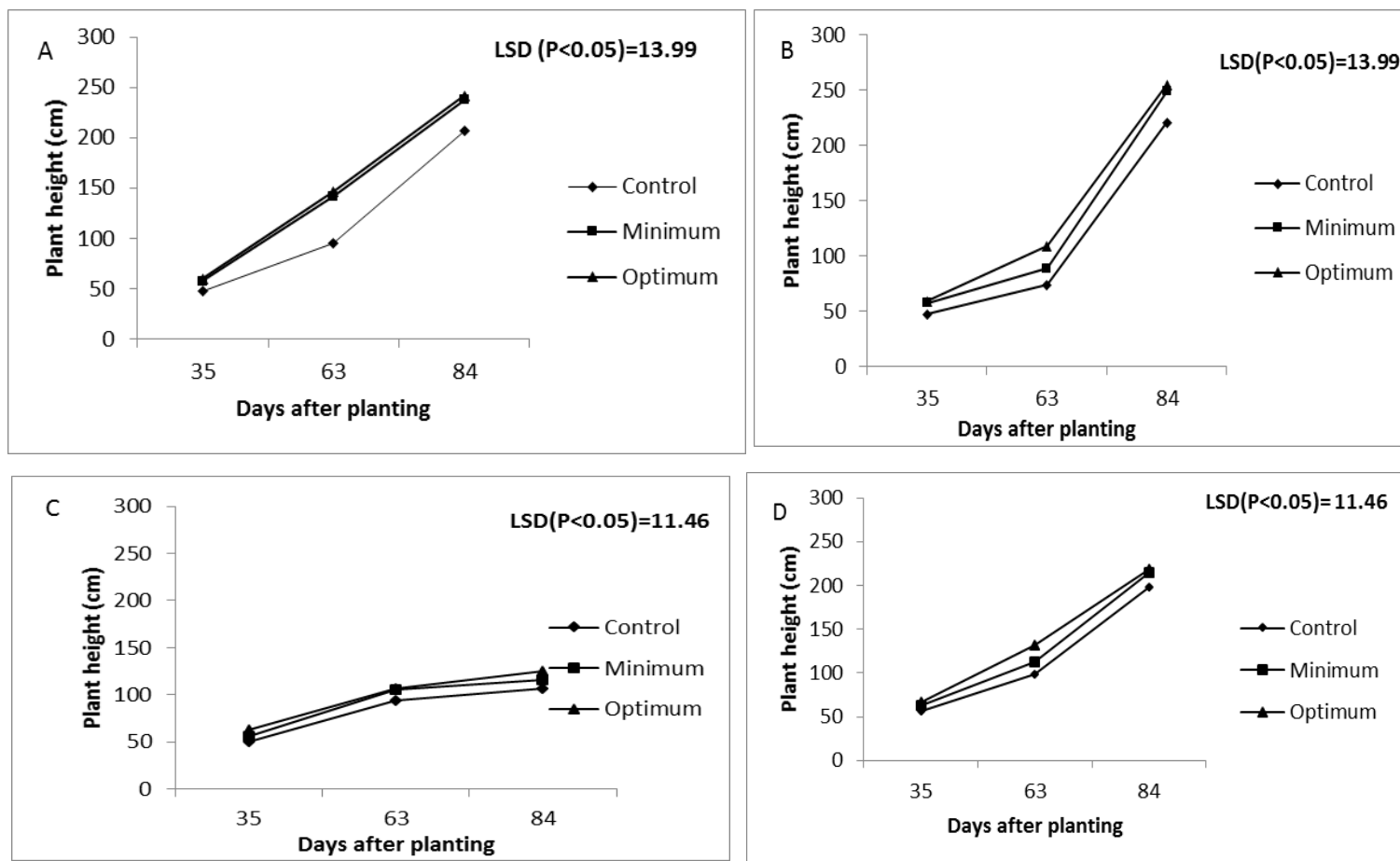


Figure 4.2: A and B= plant heights measured during 2014/2015 while C and D= plant height during 2015/2016 planting season at Ukulinga and Baynesfield sites respectively.

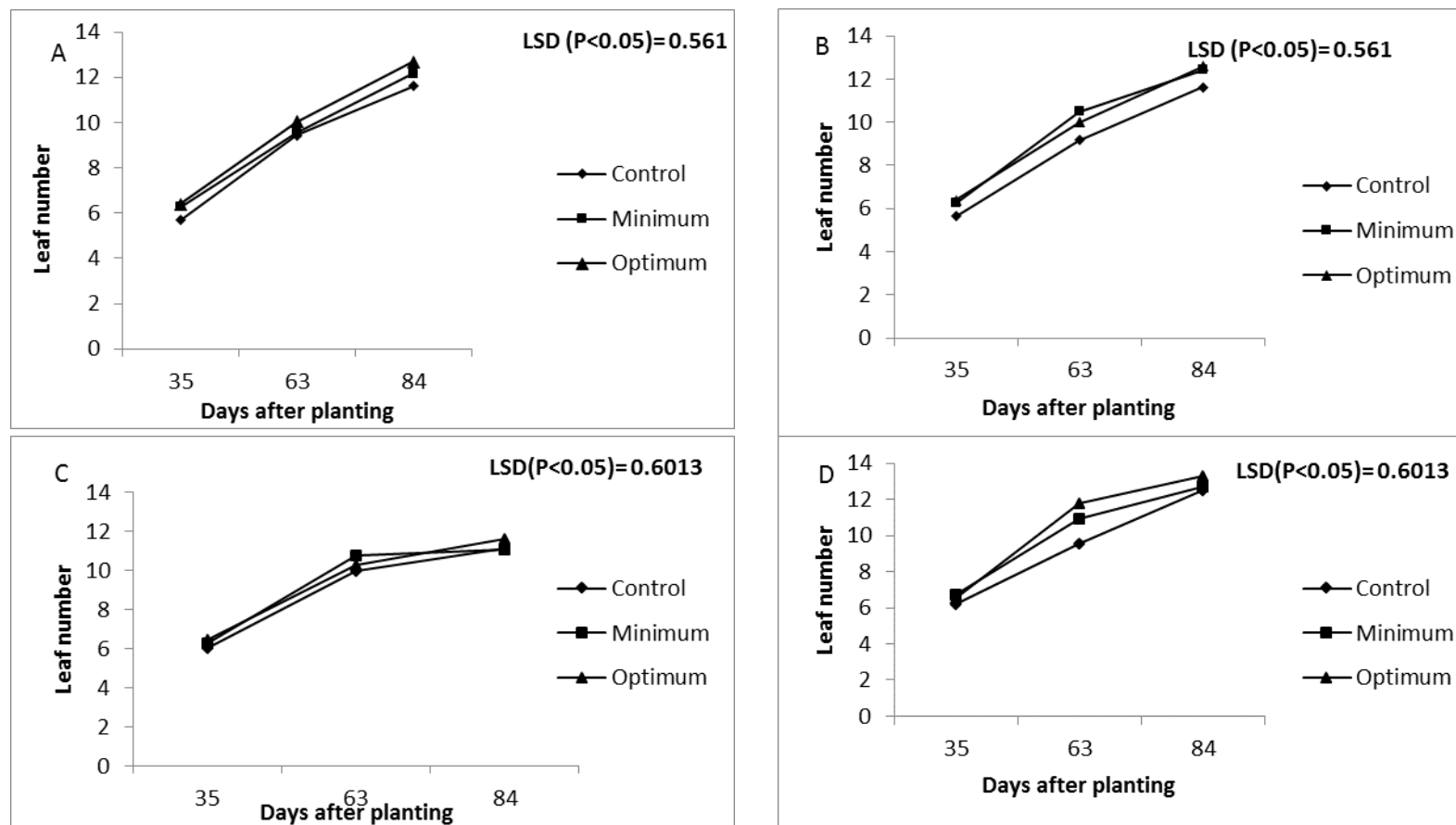


Figure 4.3: A and B= leaf number measured during 2014/2015 while C and D= leaf number during 2015/2016 planting season at Ukulinga and Baynesfield sites respectively.

During 2015/16 season, fertility levels significantly influenced ($P < 0.05$) the LAI, while the LAI was highly influenced ($P < 0.001$) by DAS, sites. In addition, their interactions except at fertility levels \times DAS \times site, which was not significantly influenced ($P > 0.05$). Leaf area index obtained under optimal fertilizer was significantly higher by 22.3% and 7.9% compared to no fertilized and minimal fertilized trials (Fig 4.4). Results of LAI during the planting seasons were consistent with observations of plant physiology and growth. There was a steady increase in LAI from 7 DAS, which decline at 32 DAS and later picked up at 42 DAS before the final declined at 58 DAS though LAI from Baynesfield site was 43.8% higher than Ukulinga (Fig.4.4). During 2014/15, the LAI was significantly influenced ($P < 0.001$) by fertility levels and sites across days after silking as well as their interactions except at fertility levels \times DAS \times site (Fig. 4.4). The plant LAI reached its peak at 18 DAS, which corresponded to when the plant attained its milk developmental stage and similar trends, was observed at both sites. The drastic declined in LAI at 32 DAS might be due to the presence of severe hail damage on the upper leaves since the health of the upper leaf canopy is particularly important for achieving maximum grain filling capacity. The observed reduction in LAI during 2015/16 season reduced plant growth due to erratic distribution rainfall. It was observed that LAI during 2014/15 was higher than 2015/16 season. During 2014/15 season, the trial establishment stage coincided with the onset and high distribution of rainfall, which enhanced the vegetative growth and rapid canopy cover.

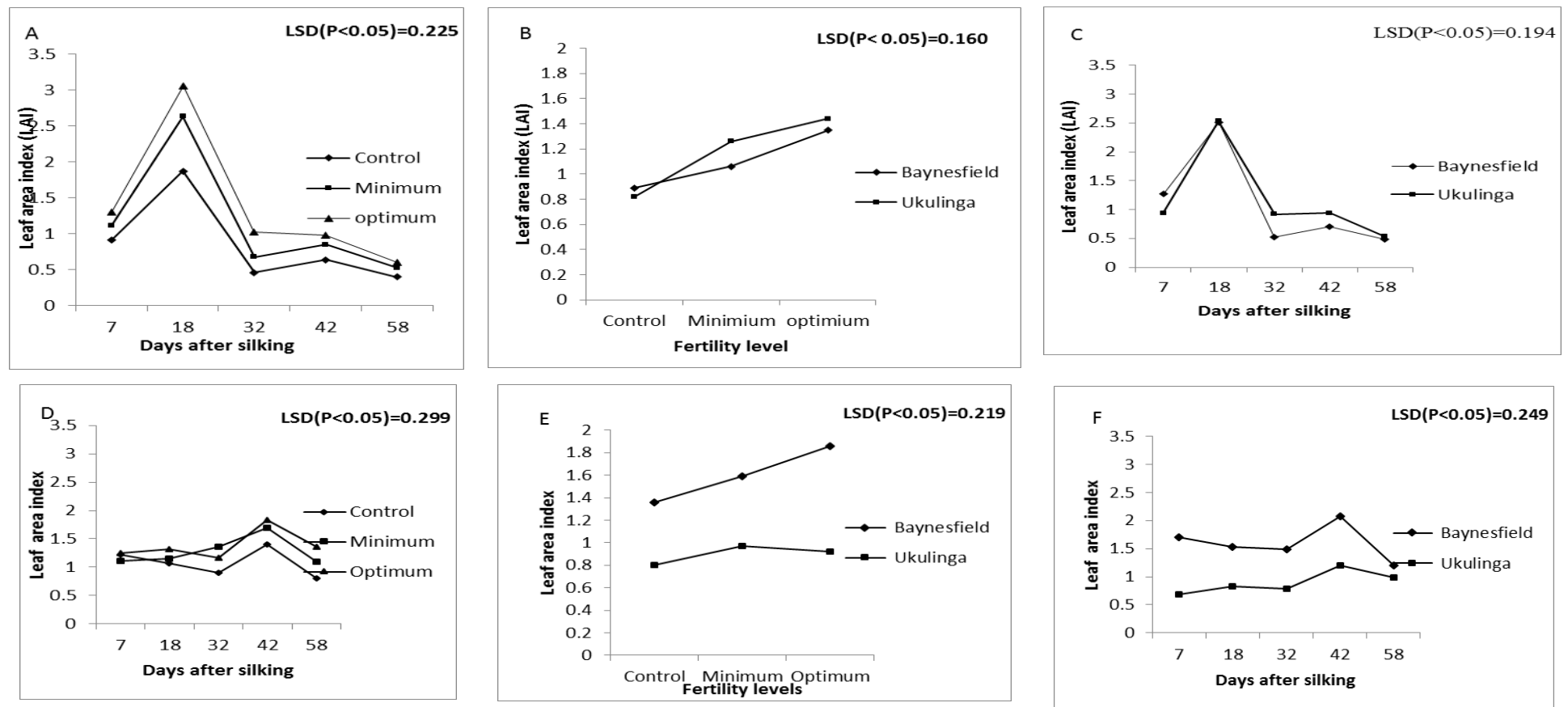


Figure 4.4: A, B and C were the leaf Area index (LAI) for 2014/2015 while D, E and F were the leaf Area index (LAI) for 2014/2016 observed at Ukulinga and Baynesfield sites respectively.

The photosynthetic rate and stomatal conductance were measured on ear leaf of the first ear which was considered to be the most physiologically active. All the measured values decreased slightly under no fertilized trials but the extent of the decrease was not distinct. Interaction of fertility levels and days after silking significantly ($P < 0.001$) influenced the plant CCI in each planting seasons (Fig. 4.5). During 2014/15, CCI was significantly ($P < 0.001$) higher under optimal fertilized conditions by 3.2% and 14% relative to minimal fertilized and no fertilized conditions. In addition, the maize CCI was significantly influenced ($P < 0.001$) by the interactions of fertility levels, DAS and sites except at fertility level \times DAS \times site. The decline in CCI across days after silking were in line with remobilization of the plant nutrients from the leaves to the ear for grain filling and ageing. During 2015/16, the maize CCI was significantly higher ($P < 0.05$) under optimal and minimal fertilized conditions compared with none fertilized conditions. Chlorophyll content index increase from 7 DAS to 32 DAS then decrease up to 58 DAS with Baynesfield having 11.2% higher CCI than Ukulinga site. The interactions of fertility level \times DAS significantly ($P < 0.001$) influenced CCI. There were decreasing trends in CCI obtained from optimal fertilized to no fertilized conditions. In addition, minimal fertilized trials had similar CCI with optimal fertilized trials across the sites (Fig.4.5).

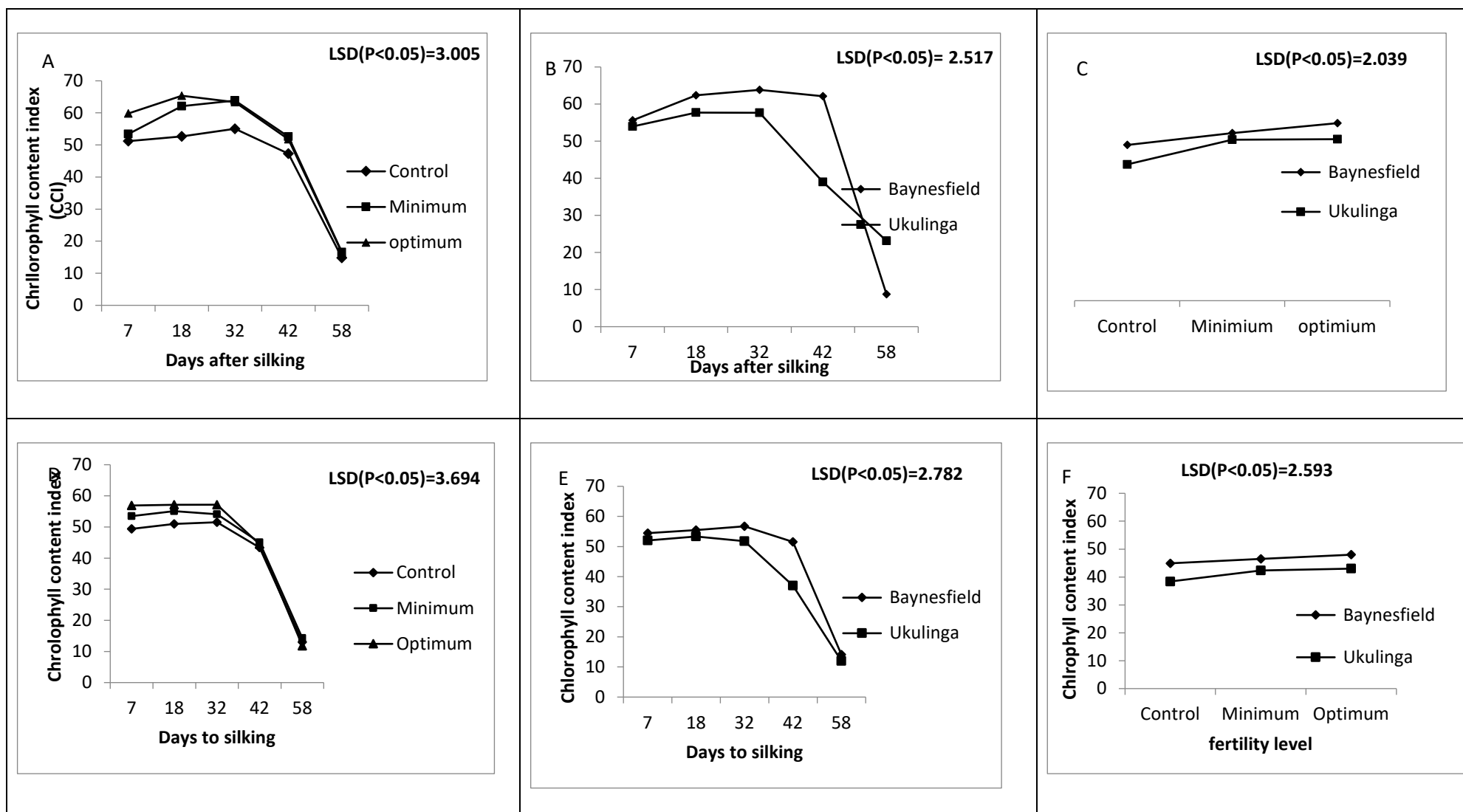


Figure 4.5: A, B and C were the leaf Area index (LAI) for 2014/2015 while D, E and F were the chlorophyll content index for 2014/2016 observed at Ukulinga and Baynesfield sites respectively.

During 2014/15, the fertility levels, sites and DAS and their interactions were significantly influenced ($P < 0.001$) by stomatal conductance (gs). Optimally fertilized maize was 39.2% and 22.2% higher than none fertilized and minimally fertilized maize. Stomatal conductance from plants from Baynesfield was 39.5% higher than Ukulinga site. In addition, increasing trend was observed from 7 DAS to 32 DAS then declined till 58 DAS. Increasing levels of rainfall during the flowering stage resulted in overall increase in gs under each treatment. During 2015/16, there were significant variations ($P < 0.001$) in the gs under different fertility levels, DAS, sites and their interactions except at the interaction of fertility level \times site which was not significantly varied ($P > 0.05$). Stomatal conductance was lower in 2015/16 compared with 2014/15 season across the sites (Fig.4.6). However, no significant variation in gs obtained under optimal fertilized and minimal fertilized treatments across the sites.

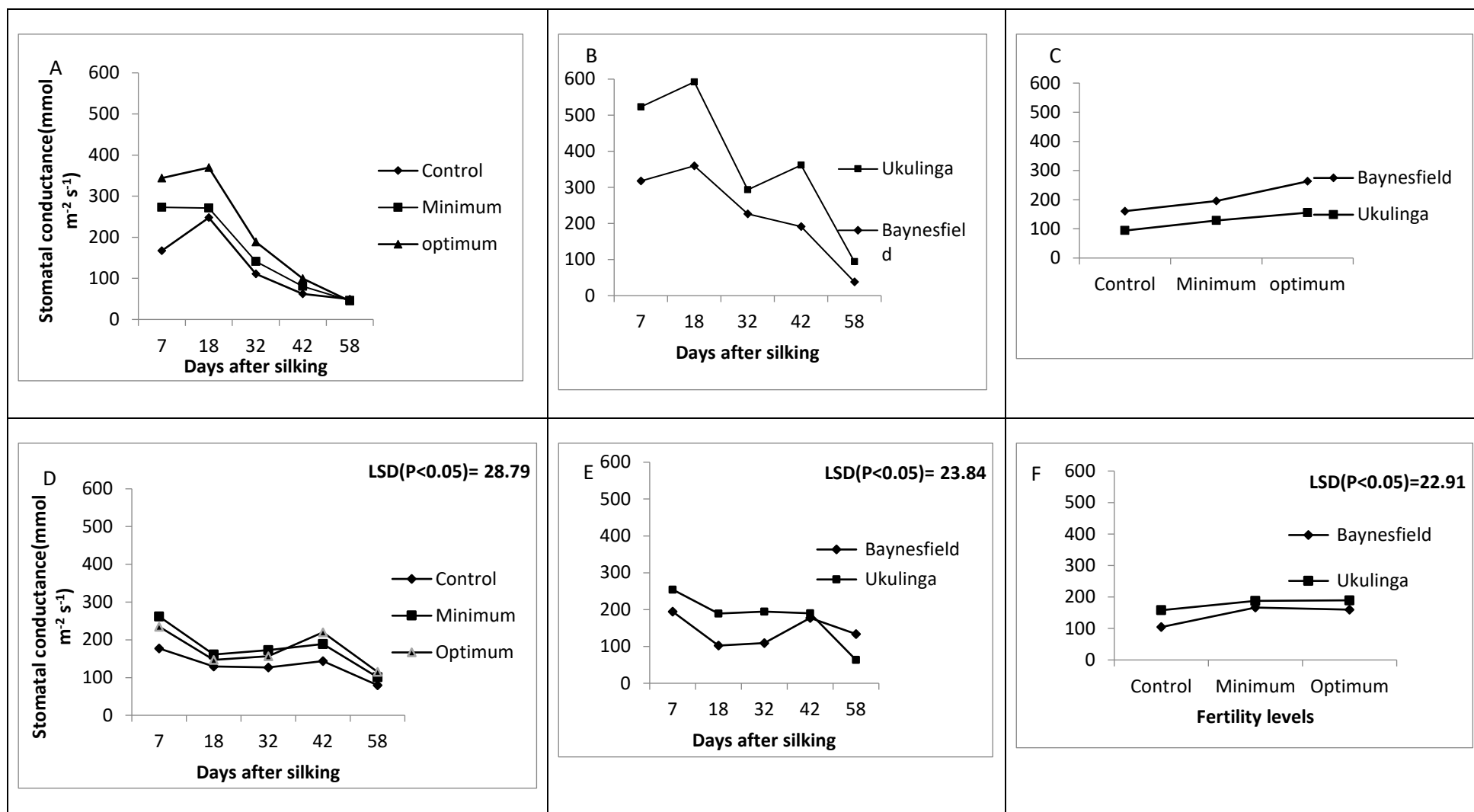


Figure 4.6: A, B and C were the stomatal conductance for 2014/2015 while D, E and F were the leaf Area index (LAI) for 2014/2016 observed at Ukulinga and Baynesfield sites respectively

During 2014/15 planting season, the heat units required for the plant to reach 50% tasselling and 50% silking occurred at 873.8 °cd and 949.6 °cd respectively. The highest mean comparison was observed for TTT and TTS at no fertilized conditions while optimal fertilized conditions had the lowest time to flowering. This result showed that application of fertilizer prolonged the time to accumulated heat units for flowering at different seasons. According to the results of Uhart et al. (1995), optimal nitrogen fertilizer increased plant growth rate and delayed maturity. Similar finding was found in 2015/16 season, increase rate of fertilizer application shortened the accumulated heat unit required for tasselling and silking than under none fertilized conditions (Table 4.2). In addition, under water deficit conditions, application of fertilizer shortened the time required to accumulate maximum heat units for flowering.

Table 4.2: Effect of fertility levels on time to tasselling and silk during 2014/15 and 2015/16 seasons

	Fertility levels (F)	TTT (°cd)		TTS (°cd)	
		2014/15 season	2015/16	2014/15	2015/16
	Control	846.10b	951.00c	918.00bc	1011.90e
	Minimal	881.80c	899.00bc	958.40de	966.90d
	Optimal	893.40cd	828.00b	972.40e	961.90d
F ¹ LSD _(P<0.05)		34.980		10.050	
F.test		P>0.05		P<0.05	
Seasons (S) ¹ LSD _(P<0.05)		26.250		8.640	
F.test		P>0.05		P>0.05	
F × S ¹ LSD _(P<0.05)		52.640		14.960	
F.test		P<0.05		P<0.001	

TTT=time to reach 50% tasselling, TTS=time to reach 50% silking and 1 = Statistics refer to the comparison between the 2014/15 and 2015/16 planting season

Yield and yield components

During 2014/15, the interaction of fertility level \times maturity stage at harvest significantly influenced ($P < 0.05$) maize yield, thousand seed weight, harvest index while, the ear length and diameter, kernel number/row and total biomass as well were strongly influenced ($P < 0.001$). However, it had no effect on seed moisture content and kernel row/ear (Table 4.3). The lowest seed yield and yield components were observed in seeds from milk stage under none fertilized conditions. Maize harvested at dent stage which corresponded to 42 DAS under minimal fertilized conditions was at par with those from optimal fertilized conditions with regards to thousand seed weight, ear length and diameter. It was noteworthy that seed yield obtained at dent stage under optimal fertilized conditions was statistically similar with seed yield harvested at physiological maturity under none and minimal fertilized conditions. Thousand seed weight, ear length and diameter of maize harvested at dent stage under optimal fertilized conditions were statistically higher than those harvested at physiological maturity under none fertilized conditions.

During 2015/16, the interaction of fertility level \times maturity stages at harvest significantly influenced ($P < 0.05$) seed yield, harvest index and strongly influenced ($P < 0.001$) thousand seed weight and total biomass. However, there was no significant interactions ($P > 0.05$) on ear length, ear diameter, kernel number/row, row number/ear and seed moisture content (Table 3.3). The planting season of 2015/16 was drier than 2014/15 which resulted in lower yield and yield components. Results of yield and yield components over the two planting seasons showed much variability between fertility levels and maturity stages. Weather data showed that 2015/16 was a drought season receiving lower-than-average rainfall and increment in atmospheric temperature. Reduction in yield components under none fertilized conditions was more pronounced during 2014/15 than 2015/16 season which might be due to higher rainfall received which enhanced the rate of nutrient uptake from the soil.

Overall, the maturity stage at harvest influenced the yield, thousand seed weight, and ear diameter and kernel row/ear and seed moisture content at both seasons. Maize yield, ear length, kernel number/row, total biomass and harvest index varied across the sites with Baynesfield having higher yield components than Ukulinga site.

Table 3.3 A: Interactive effect of fertility level and maturity stages on yield and yield components during 2014/15 and 2015/16 seasons

Seasons	Fertility levels (F)	Maturity stages (M)	Y(tons/ha)	TSW (g)	EL(cm)	ED (cm)	KN/R	KN/E	SMC (%)	TB (t/ha)	HI (%)
2014/15	Control	Milk stage	3.17a	270.08a	21.36a	6.41a	49.75d	11.67a	78.10a	-	-
	Minimal		3.72b	310.84a	26.25b	6.66a	50.12cd	12.33a	73.89a	-	-
	Optimal		4.42c	310.97a	28.66c	7.02b	51.50d	12.67a	76.43a	-	-
	Control	Dent stage	5.06d	490.01b	27.44bc	7.73c	47.12bc	11.96a	60.00a	-	-
	Minimal		6.05de	580.51c	28.50c	8.47c	49.50cd	12.71a	58.62a	-	-
	Optimal		6.65e	590.02c	28.96c	8.30de	51.25d	12.65a	57.67a	-	-
	Control	Physiological maturity	6.54e	440.17b	27.21bc	8.12d	36.62a	11.52a	30.65a	12.73a	40.57a
	Minimal		6.68e	580.51c	27.96bc	8.91f	44.50b	12.33a	30.70a	16.90b	50.09b
	Optimal		7.23f	792.00d	29.00c	9.52g	49.85cd	12.63a	29.24a	18.76c	56.17b
	LSD(P<0.05) FL×M		P<0.05	P<0.001	P<0.001	P<0.001	P<0.001	P>0.05	P>0.05	P<0.001	P<0.05
	P- value		0.512	70.345	2.357	0.335	3.140	0.601	4.065	1.828	6.228
2015/16	Control	Milk stage	3.54a	162.7a	19.59a	7.16a	23.06a	11.38a	76.34a	-	-
	Minimal		4.81b	191.4ab	23.44a	7.78a	28.31a	13.00a	81.55a	-	-
	Optimal		4.69b	209.4b	24.53a	7.99a	30.62a	13.71a	80.11a	-	-
	Control	Dent stage	4.88b	421.20c	20.62a	7.63a	24.56a	11.62a	60.89a	-	-
	Minimal		4.54	468.7d	22.12a	7.72a	30.00a	12.50a	58.99a	-	-
	Optimal		5.13b	497.6d	22.81a	8.13	34.94a	12.75a	59.36a	-	-
	Control	Physiological maturity	4.60b	421.20c	18.63a	7.64a	26.94a	11.50a	23.43a	5.15a	45.00a
	Minimal		5.30c	489.50d	21.66a	8.22a	30.69a	12.58a	24.96a	6.11a	50.00ab

Optimal	5.70c	562.80e	21.69a	8.06	36.50a	13.00a	23.88	7.43b	56.00b
F.test	P<0.05	P<0.05	P>0.05	P>0.05	P>0.05	P>0.05	P>0.05	P<0.001	P<0.05
LSD(P<0.05) F×M	0.682	64.234	28.780	0.478	2.486	1.266	4.702	0.058	1.223

Y= seed yield, TSW= thousand seed weight, EL=ear length, ED=ear diameter, KN/R=kernel number/row, KN/E= row number/ear, SMC= seed moisture content, HI=harvest index, TB=total biomass and 1 = Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons.

Table 3.3 B: Interactive effect of fertility level and maturity stages on yield and yield components during 2014/15 and 2015/16 seasons

Seasons	Fertility levels (F)	Y(tons/ha)	TSW (g)	EL(cm)	ED (cm)	KN/R	KN/E	SMC (%)	TB (t/ha)	HI (%)
Overall LSD($P_{<0.05}$)	F ¹	0.218	8.84	1.282	0.256	0.668	0.430	1.656	0.878	4.151
		P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P>0.05	P>0.05	P<0.001	P<0.001
	M ¹	0.239	8.040	0.959	0.160	1.216	0.433	1.722	-	-
		P<0.001	P<0.001	P>0.05	P<0.001	P>0.05	P<0.001	P<0.001	-	-
	Site (S) ¹	0.137	8.130	0.690	0.126	1.107	0.296	1.313	0.424	1.271
		P<0.05	P>0.05	P<0.05	P>0.05	P<0.001	P>0.05	P>0.05	P<0.001	P<0.05
	Year(Y) ¹	0.137	8.130	0.690	0.126	1.107	0.296	1.313	0.424	1.271
		P<0.001	P<0.001	P<0.001	P<0.05	P<0.001	P>0.05	P>0.05	P<0.001	P<0.001
	F×M ¹	0.3797	13.44	1.726	0.315	1.792	0.702	2.770	-	-
		P>0.05	P<0.001	P<0.001	P>0.05	P<0.001	P>0.05	P>0.05	-	-
	F × M × Y ¹	0.417	21.52	2.221	0.4043	2.904	0.926	2.151	-	-
		P>0.05	P<0.05	P>0.05	P>0.05	P<0.05	P>0.05	P>0.05	-	-
	F × M × S ¹	0.417	12.47	2.221	0.4043	2.904	0.926	2.151	-	-
		P<0.05	P<0.001	P>0.05	P>0.05	P<0.05	P>0.05	Ns	-	-
	F×M×S×Y ¹	0.621	32.46	3.019	0.550	4.402	1.277	3.862	-	-
		Ns	P<0.001	P>0.05	P>0.05	P>0.05	P>0.05	P>0.05	-	-

Y= seed yield, TSW= thousand seed weight, EL=ear length, ED=ear diameter, KN/R=kernel number/row, KN/E= row number/ear, SMC= seed moisture content, HI=harvest index, TB=total biomass and 1 = Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons.

Discussion

The soil fertility status during plant growth and development has a modifying effect on its seed production as observed from the two experimental sites used. High soil fertility status at Baynesfield site coupled with high distribution of rainfall enhanced the plant growth and physiological development compared to Ukulinga site. The remarkable increase in plant height attained by optimal fertilized trials could be explained by the efficiency of nitrogen and phosphorus source supplied. The soil fertility status especially the nitrogen levels dictated maize plants growth. Since, maize is a strong nitrogen scavenger. The improved nutrient availability through optimal fertilizer application enhanced root functions through increased leaf canopy and root growth, which resulted in enhanced soil water capture. Thus, stomatal conductance, chlorophyll content and leaf area index improved under optimal fertilized soil conditions. The differences in photosynthetic rate at each treatment during the reproductive stage could be attributed to variation in soil fertility experienced. However, erratic rainfall distribution hindered the uptake of soil nutrients as seen during 2015/16 season. The steady increase in physiological parameters measured at both sites from 7 to 32 DAS might be due to the presences of more active photosynthetic leaves compared to 58 DAS which corresponded to physiological maturity when there was high rate of leaf senescence due to ageing as well as nutrients remobilization from the lower to higher leaves and finally to ear occurred.

These results corroborated the findings of Tajul et al. (2013) who reported highest SPAD value and nitrogen content in the plants treated with 220 N kg/ ha regardless of planting density. Stomatal conductivity was lower under none fertilized soil conditions compared to minimal and optimal fertilized conditions. This implied reduction in available CO₂ and lowers levels of photosynthetic pigments. The low response of maize canopy characteristics in 2015/16 season suggested that canopy growth was greatly influenced by water availability. Under limited water supply, the reduction in canopy size allowed the plant to maximize the available soil for the completion of its life cycle (Kirkham, 2014). The reduction plant growth and physiological traits observed under no fertilized treatments and during

2015/16 season might be due to reduced photosynthesis emanating from reduced CO₂ assimilation and fixation because of stomatal closure and reduced chlorophyll in the leaves. The photosynthetic rate and stomatal conductivity of none fertilized plants were significantly lower compared with plants under fertilized conditions. Fertility levels help to improve the rate of photosynthesis and stomatal conductance. Reduction in plant height, leaf number and leaf area index helped the plants adaptation strategy by minimising water loss during drought period (Mabhaudhi and Modi, 2011). Similar results showing reduction in maize plant height, leaf number and leaf area index were found in the literature (Efthimiadou et al., 2010, Faheed et al., 2016).

The fluctuation in chlorophyll content index, stomatal conductance and leaf area index across days after silking might be due to fluctuation in the available soil water caused by erratic distribution of rainfall. The steady increase in leaf area index from 7 DAS enhanced more production of photosynthates. These results were similar to the finding of Yi et al. (2010) who observed that leaf area index was maintained at a high level from maize developmental stage R₁ to R₃ which benefit assimilation, production and transportation in the plants but declined towards physiological maturity (R₆). The variations in physiological traits and growth parameters in responses to soil fertility levels across seasons and sites might be attributed to differences in agro-ecological conditions, degree of variability of seasonal rainfall, length of growth period and tillage practice systems (Haruna and Nkongolo, 2013).

The total biomass production and harvest index were obtained only at physiological maturity for the two planting seasons, which varied across the sites due to differences in soil fertility status and rainfall pattern received. The results were in line with observations of growth and physiology obtained for the corresponding planting seasons. Though 2015/16 had lower total biomass and harvest index because of severe drought. The observed low biomass under none fertilized conditions relative to minimal and optimal fertilized conditions was consistent with the trend observed for stomatal conductance, chlorophyll content and plant growth parameters. The effect of reduced CO₂ assimilation, low photosynthetic rate and reduced leaf canopy under none fertilized conditions might have led to

production of lesser biomass and harvest index. The maintenance of green leaves through optimal fertilization for a long period at grain-filling stages (R_3 to R_5) would have enabled the crop to intercept radiation for a long period and increased biomass accumulation. Reduction biomass production in non-fertilized plants could be either reduction in the amount of radiation intercepted by the canopy or decrease in the efficiency with which the intercepted radiation is used to produce dry matter or its combinations.

Previously, improvement in maize yield have been associated with increase in total biomass and harvest index. Biomass accumulation propels the force for mineral nutrient uptake and assimilation (Lorenz et al., 2010). Though, Gul et al. (2015) explained that a gradual increase in dry matter production of crop from knee high to maturity stage irrespective of fertility levels. However, harvest index reflects the efficiency of dry matter partitioning and increase as demand for nutrients of relatively large concentrations in the grain increased (Sinclair, 1998). Thus, for optimal yield in maize under adequate rainfall conditions increase in biomass accumulation as well as partitioning of dry matter to the grain will vary with the level of soil fertility available for nutrient uptake and remobilization. Results of the measured yield components (grain yield, thousand seed weight, kernel number/row, kernel row/ear, ear length and diameter, seed moisture content) showed much variability among the fertility levels and stages of maturity at harvest over the two seasons. The observed similarity in minimal fertilized maize harvested at dent stage (42 DAS) with optimal fertilized conditions for thousand seed weight, ear length and diameter could be attributed to efficient utilization of initial nutrient uptake from the soil. Also, the similarity in grain yield obtained from optimal fertilized dent stage with those harvested at physiological maturity under no and minimal fertilized conditions indicated the importance of adequate soil fertility status on the grain filling period which might have increased the rate of assimilate in the kernel. Bender et al. (2013) reported that maximum rate of dry weight production occurred between V_{10} and V_{14} and between R_2 and R_4 which coincided with the maximum measured rates of nutrient uptake.

The increase in thousand seed weight, ear length and diameter of maize harvested at dent stage under optimal fertilized conditions than those harvested at physiological maturity without fertilizer application showed that adequate fertilization at the appropriate time elevated total nutrient uptake and enhanced plants maximum utilization. Thus, leading to higher yield in maize harvested earlier but closer to its physiological maturity than those harvested at physiological maturity under poor or average soil fertility status. No distinct trend observed in yield component except at grain yield during 2015/16 showed that application of fertilizer during drought period or in the presence of erratic distribution of rainfall led to depletion of soil water. It has no positive effect on the maize yield, because the soil solution is essential for nutrient uptake and utilization since maize is an efficient user of nutrient and water in terms of total biomass production. During the grain filling stage, amount of rainfall received was below the water requirement for the stage causing reduction in yield components. Similar result was observed by Ghassemi-Golezani and Tajbakhsh (2012) who stated that maximum grain weight of maize was mainly influenced by grain filling rate, which determines final grain yield. Wakene et al. (2014) reported grain yield increment was recorded due to N-fertilizer application as compared to the control treatment. Increase in seed weight might be due to enhancement in source efficiency as well as sink capacity. Grain yield is a function of seed number/row and seed weight. Rahmani et al. (2014) reported that ear diameter and seed weight are the most important yield component because it has most positive direct effect on conservable grain yield. This result agreed with the above-mentioned authors, that optimum fertilization has positive effect on growth and yield component of SC701 hybrid maize. It further found out that harvesting optimally fertilized SC701 hybrid at dent stage (42 DAS) under a stress-free conditions has higher yield potentials than those obtained at physiological maturity under poor soil fertility status. At low nitrogen and phosphorus supply, crop growth rate slowed down causing reproductive structures to decline resulting in lower maize grain yield.

Conclusion

Maize seed production depends greatly on water availability, fertilization and relevant management practices, which varies among locations and seasons. Stages of maturity at harvest have great impact on seed yield and yield components of maize. Understanding of various management practices such as effect of stage of maturity at harvest and fertilizers requirement, which are higher in hybrids than landrace, is imperative to boost maize seed production. Although optimal recommended fertilizer dosage, which can improve grain yield has a high cash cost and riskier for the resource poor farmers. Hence, increase their reluctance in applying fertilizers. However, none adherence to the recommended fertility dosage by smallholder farmers brings subsequent reduction in seed yield. Also, in the presence of abiotic stress, harvesting a stress-free optimally fertilized maize at dent stage can maximize the yield potential of a crop and will be the best option than allowing it to reach physiological maturity under poor soil fertility status or adverse weather conditions. The understanding of critical needs during maize seed development would help farmers weigh crop management options as climate patterns change and weather events become extreme.

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CHAPTER 5

Effect of planting date and harvesting stage on seed quality maize under small-scale farming conditions¹

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Abstract

Matching different management practices during seasonal changes in weather conditions might improve seed yield and quality. The objective of this was to determine interactive effect of three planting dates and maturity stages on the physiological quality of maize seeds. Field trials were conducted at the university of KwaZulu-Natal's research farm during the two summer seasons. A split plot design where planting date (main factor) and harvesting time (sub plots) replicated ($\times 4$) was used. Trials were harvested at milk, dent and physiological maturity stages based on its milk line and moisture content, then dried. Seed quality was evaluated using a standard germination test, vigour indices and an electrical conductivity test. The interaction effect of planting date and harvesting stage significantly ($P < 0.05$) affected daily germination, mean germination time, speed of germination, root: shoot ratio, thousand seed weight and seedling fresh and dry mass. Physiologically mature seeds under early- and mid-planting had the best germination performance during warmer and drier seasons, respectively. Although, seed lots harvested at dent stage under favourable weather conditions gave higher seed quality than physiological mature seeds from extreme weather conditions. For optimal seed quality, harvesting at physiological maturity under early- or mid-planting is recommended.

Keywords: germination, hybrid, seed, vigour, weather

Introduction

Seed development is a complex process involving genetic, metabolic, physiological pathways and environmental factors. Maturation on the other hand, commences at the end of seed development involving enlargement of endosperm to accommodate the synthesis of storage product and accumulation (Li et al 2014). Studies on seed development and maturation have become important for seeds to be harvested at proper time and ensure high viability and vigour. Seed quality can be limited by environmental conditions prior or after physiological maturity. Thus, for optimal seed quality, planting at the appropriate time to fit the specific hybrid maturity length is critical. The response of each hybrid at each maturity stage to differences in weather conditions is important for improving yield and hence enhancing food security especially in developing countries. Maize 'SC701' is one of the common southern African hybrids (BFAP 2011). The cultivar's desired traits are large ear size, long shelf life, high yield and moderate drought tolerance (ARC 2014). It is a late maturing cultivar requiring an average of 1028 growing degree days (GDD) from emergence to physiological maturity. It also requires an average of 6.4 mm day^{-1} water from the 12-leaf stage to full dent stage (Darby and Lauer 2002, Akinnuoye and Modi 2015)

Maize is an efficient soil nutrient using crop and its productivity largely depends on the length of the growing season and heat units accumulated. Variability in planting conditions is mainly caused by ambient temperature leading to differences in accumulated heat units, soil water, photosynthetically active radiation and level of atmospheric carbon dioxide (Hampton *et al.*, 2013). Assimilate translocation and grain-filling duration and rate are directly influenced by changes in ambient temperature. Extreme temperatures have a strong negative effect on germination rate, emergence time and germination uniformity (Hampton, *et al.* 2013, Ahmad *et al.*, 2014). Gray and Brady (2016) reported that plant developmental responses to

environmental changes could alter initiation of developmental events and final form of organs. The severity of extreme temperature depends on its duration and crop developmental stage. Limitation in soil water during the reproductive stages causes reduction in net assimilation rate and decreases the size of the sink thereby lead to lower kernel dry weight. The viability and the performance of progeny seeds during the early stages of germination might be related to the environmental conditions experienced during its development and maturation. Hampton *et al.* (2013) explained that high temperatures before developing seeds attain maximum dry weight (physiological maturity) is likely to inhibit the supply of assimilates necessary to synthesise seed storage compounds needed for germination.

Vigour and viability differences arise early during seed developmental, as seed dry weight is accumulated (Marcos Filho 2015). Seed producers are faced with the daunting task of harvesting seed either early or lately during increment in weather conditions to prevent loss yield and quality. Varying planting dates and stages of maturity at harvest might enhance maize yield, quality and minimise risks under adverse weather conditions. Optimal planting dates are regional and vary across Southern Africa due to seasonal changes in weather conditions. It is important to study the effect of planting at different dates as well as the effect of harvesting before the ears are subjected to unfavourable conditions. Several studies have focused on physiological responses of maize seed germination at different stages of maturity (Alabi *et al.*, 2005, Jacob Junior *et al.*, 2014, Hampton, *et al.* 2013); the environmental effects on the progeny seeds remain largely unknown in relation to the seed quality. To understand the response of maize seed quality to different environmental conditions, it will be important to investigate the changes during maturation in seed germination and vigour under different planting dates.

Therefore, the objective of this study was to determine the interaction of different planting dates and harvesting stages of SC701 maize seed quality under smallholder farming conditions. It was hypothesised that the physiological quality of seeds harvested earlier under favourable weather conditions will have higher seed quality than seeds obtained at physiological maturity under extreme weather conditions.

Materials and methods

Site description, crop management and field layout and experimental design were described in the previous chapter.

Data collection

Weather data

Daily weather data were obtained from an automatic weather station (AWS) Agricultural Research Council-Institute for Soil, Climate and Water (ARC-ISCW) network of automatic weather stations located within Ukulinga Research Farm. Weather parameters that were considered were rainfall (mm), maximum (T_{max}) and minimum (T_{min}) air temperature ($^{\circ}\text{C}$).

Crop phenology

Time to reach 50 % tasselling (TTT) and 50% silking (TTS) were taken as number of calendar days taken to reach 50% tasselling and silking from the date after planting. It was recorded based on the appearance of tassels and silks in 50% of the plants in each plot and expressed in days and later converted to thermal time using method described by McMaster and Wilhelm (1997)

$$\text{GDD} = \frac{(T_{max} + T_{min})}{2} - T_{base}$$

Where, GDD = growing degree days ($^{\circ}\text{Cd}$), T_{max} and T_{min} = maximum and minimum temperatures, respectively, and T_{base} = base temperature. If $T_{\text{max}} < T_{\text{base}}$ then $T_{\text{max}} = T_{\text{base}}$ and if $T_{\text{min}} < T_{\text{base}}$ then $T_{\text{min}} = T_{\text{base}}$, $T_{\text{base}} = 10^{\circ}\text{C}$

Seed harvest

A standardised maize developmental stage system based on the milk line and the kernel moisture content was used to identify harvesting stages. Moisture content has been frequently used in the farm to decide the best harvesting time and milk line can be visually use to monitor kernel maturation prior to physiological maturity (Ritchie *et al.*, 1993, Santos *et al.*, 2005, Henning *et al.*, 2011). Maize was harvested at 0%, (milk stage) 50% (dent stage) and 25% (physiological maturity) solid endosperm. Harvesting at milk, dent and physiological maturity stages coincided with 18 (R_3), 42 (R_5) and 58 days after silking (R_6) developmental stages, respectively, according to (Nielsen 2016).

However, during 2015/16 season harvesting was carried out only at milk and dent stages in each planting date due to the rapid invasion of wild pigs, which did allow the crop to reach physiological maturity. At each harvest, six ears were randomly selected in each plot and first ear from the top of the plant was harvested by hand. Thousand-seed weight (TSW) was determined by count hundred seed from each treatment and multiplying by 10. Harvested ears were placed on benches in the glasshouse under dry conditions and allowed to dry < 12% moisture content. Dry seed from the middle and basal sections of maize ears were threshed by hand and stored at 4°C in the cold room until further analysis.

The seed moisture content (SMC) was determined by wet weight basis

Electrical conductivity (EC)

A representative sample of seeds (about 1 kg) from each treatment reduced in the laboratory in order to obtain the working sample was used. Electrical conductivity was measured using an EC meter (R&A CM100 Model Single Cell Analyzer Reid and Associates South Africa). Hundred seeds from each treatment were individually rinsed in distilled water to remove the dirt around the seed coat before weighing then put into cells; each cell was arranged inside a tray, filled with 2 ml of distilled water. Electrical conductivity for each treatment was measured over a period of 24 hours. It was then computed according to the formula below:

$$EC = \frac{\text{micromhos}}{\text{Weight of seed}} \text{ (g)}$$

Laboratory standard germination test

Germination test were carried out on the seed harvested at each harvesting stages and planting dates according to (ISTA 2016). Hundred seeds were randomly selected from each treatment and each experimental unit consisted of 25 seeds with four replications. The rolled paper towels were put in sealed plastic bags to avoid moisture loss and incubated Labcon growth chambers (Labcon laboratory Equipment Germany L.T.I.E) with temperature set at 25°C for 7days. Daily counting of germination was based on defining germination as radicle protrusion of 2 mm. Observations were made daily for daily germination (DG), final germination percentage (FG) on day 8, according to AOSA (1992) guidelines. Upon termination of the experiment, 10 seedlings from each replicate and treatments were randomly selected for vigour indices which were root length (RL) and shoot length (SL), root: shoot ratios (R:S), seedling vigour index (VI), fresh mass (FM) and dry mass (DM). Seedling dry mass (DM) was determined by oven-drying seedlings at 70°C for 72 hours and weighing them afterwards.

Seedling vigour was calculated according to the formula by Abdul- Baki and Anderson (1973)

Seed Vigour Index (VI)

$$= (\textit{shoot} + \textit{root length}) \times \textit{germination percentage}$$

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

$$MGT = \frac{\sum fx}{\sum f}$$

where: MGT = mean germination time,

f = the number of seed completing germination on day x, and

x = number of days counted from the beginning of germination.

Germination velocity index (GVI) which measure speed of seedling germination was calculated according to Maguire (1962) formula:

$$GVI = \frac{G_1}{N_1} + \frac{G_2}{N_2} + \dots \frac{G_n}{N_n}$$

where: GVI = germination velocity index,

G₁, G₂...G_n = number of germinated seeds in first, second... last count, and

N₁, N₂...N_n = number of sowing days at the first, second... last count.

Description of statistical analysis

Bartlett's test was done to determine homogeneity of variances for all measured variables. Significant differences at 5% level of significance was observed indicating common variance among the planting dates in each season. Hence, data for planting dates were pooled for subsequent analysis for crop phenology and seed germination characteristics. Multiple comparison tests were done using Fisher's least significant difference (LSD) at 5% level of significance.

Results

Weather data

The weather data obtained for 2014/2015 planting season agreed with the long-term weather data for Ukulinga site. However, weather data for 2015/16 deviated marginally with an average temperature increase of 2.3°C (November to March) from the observed annual mean maximum temperatures for the months. Comparing the two seasons, maximum and minimum temperatures were higher in 2015/16 (28.1°C and 15.6°C) than 2014/15 (24.9°C and 14.9°C respectively). This was not in uniformity with the long-term maximum and minimum temperatures of 25.6°C and 16.9°C (Fig 4.1). This might have resulted in longer heat units' accumulation for early-planted maize and quickens in seed development during 2015/2016 as compared with 2014/15 season. There were no statistical differences in heat unit needed to attained tasselling and silking in maize plants under mid-planting date while crops from late planting date had the least heat units to attain tasselling and silking in both seasons (Table 1).

Table 5.1: Phenological stages in SC701 maize at different planting dates during the 2014/15 and 2015/16 seasons.

Seasons (S)	Planting dates (P)	TTT (°cd)	TTS (°cd)
2014/15	Early	873.80bc	949.60b
	Mid	873.90bc	937.40b
	Late	835.10b	898.70a
2015/16	Early	892.80c	980.30a
	Mid	843.80bc	904.10b
	Late	736.20a	883.60a
LSD(P<0.05) Seasons		13.250	4.510

LSD($P<0.05$) Planting dates	22.860	4.860
LSD($P<0.05$) Seasons \times Planting dates	27.440	6.270

TTT and TTS = time to reach 50% tasselling and silking respectively, Values in the same column sharing the same superscript letter are not significantly different ($P < 0.05$).

Comparing the rainfall received during the early, mid and late planting dates in the two seasons, 2014/15 season (407.9 mm, 371.6 mm and 267.2 mm) received more distribution of rain than 2015/16 (444.8 mm, 360.7 mm and 208.4 mm) respectively (Fig 5.1). Almost 80% of rainfall received during 2015/16 was received from January- March while the rest were sparingly distributed. In addition, there were more days of no rainfall during the seed developmental stage of the crop in 2015/16 than 2014/15 season (Fig 5.1). The observed results suggested the possibility of intermittent water stress was higher in 2015/16 than 2014/15 season.

Early and mid-planting dates had adequate precipitation and temperature, which was most suitable for seed development compare to late planting. Seed planted lately experienced low minimum temperature and rainfall at some point during seed development. There were days where the average temperature was below 16°C. In addition, the total rainfall received during late planting in the 2014/15 and 2015/16 seasons were far below the recommended water requirement for dry land maize production (Fig. 5.1). The weather data showed that 2014/15 was more conducive for seed development than 2015/16 season though incidences of hail storms were more frequent during 2014/15 season than during 2015/16 (Fig. 5.1).

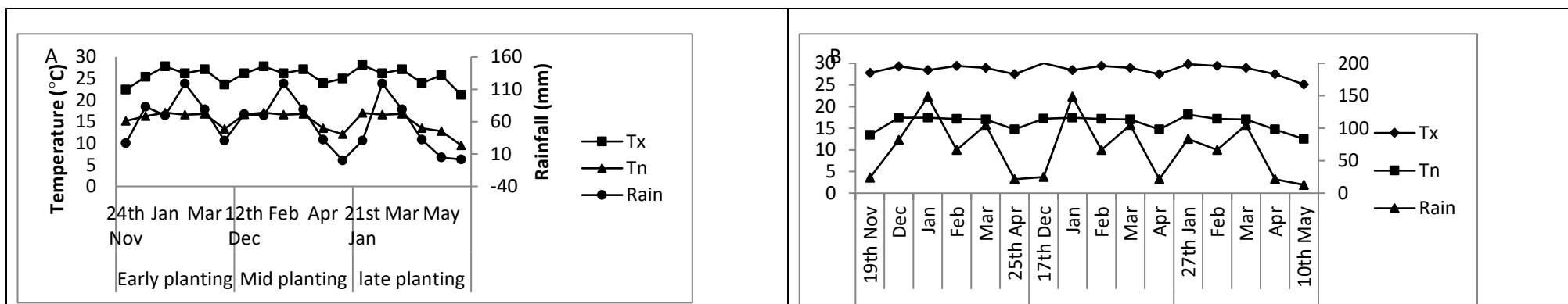


Figure 5.1: Variation in monthly rainfall (rain) and maximum (T_x) and minimum (T_n) temperatures ($^{\circ}\text{C}$) recorded during A = 2014/15 and B = 2015/16 planting seasons at Ukulinga site Pietermaritzburg South Africa.

Crop phenology

The time to reach 50% tasselling and 50% silking were shown to be significantly affected by seasons and planting dates (Table 5.1). It showed significant differences ($P < 0.05$) among planting dates. Time to reach 50% tasselling and silking were statistical similar in early (873.8 °cd, 949.6 °cd) and mid planting dates (873.9 °cd, 937.4 °cd) while it was shortened in late planting (835.1 °cd, 898.7 °cd) during 2014/15 season. Contrarily, in 2015/16 plants from early planting (892.8 °cd, 980.3 °cd) had prolonged time in reaching tasselling and silking followed by plant from mid planting (843.8 °cd, 904.1 °cd) but late planting (736.2 °cd, 883.6 °cd) had the shortest period (Table 5.1).

Standard germination test

The interaction of planting date \times harvesting stage significantly influenced the daily germination ($P < 0.001$) in both seasons. During 2014/15 season, the daily germination of seed lots harvested at dent stage and physiological maturity under early planting date were at par. Seed lots from dent stage attained maximum germination within 4 days while those seeds from physiological maturity attained maximum germination within 3 days (Fig. 5.2). Distinct differences in daily germination were observed in seed lots harvested at different stages under mid and late planting dates (Fig. 5.2). The least daily germination percentage was in seed lots harvested at milk stage under late planting date. During, 2015/16, seeds from dent stage under mid planting outperformed those seed from milk stage in all the planting dates.

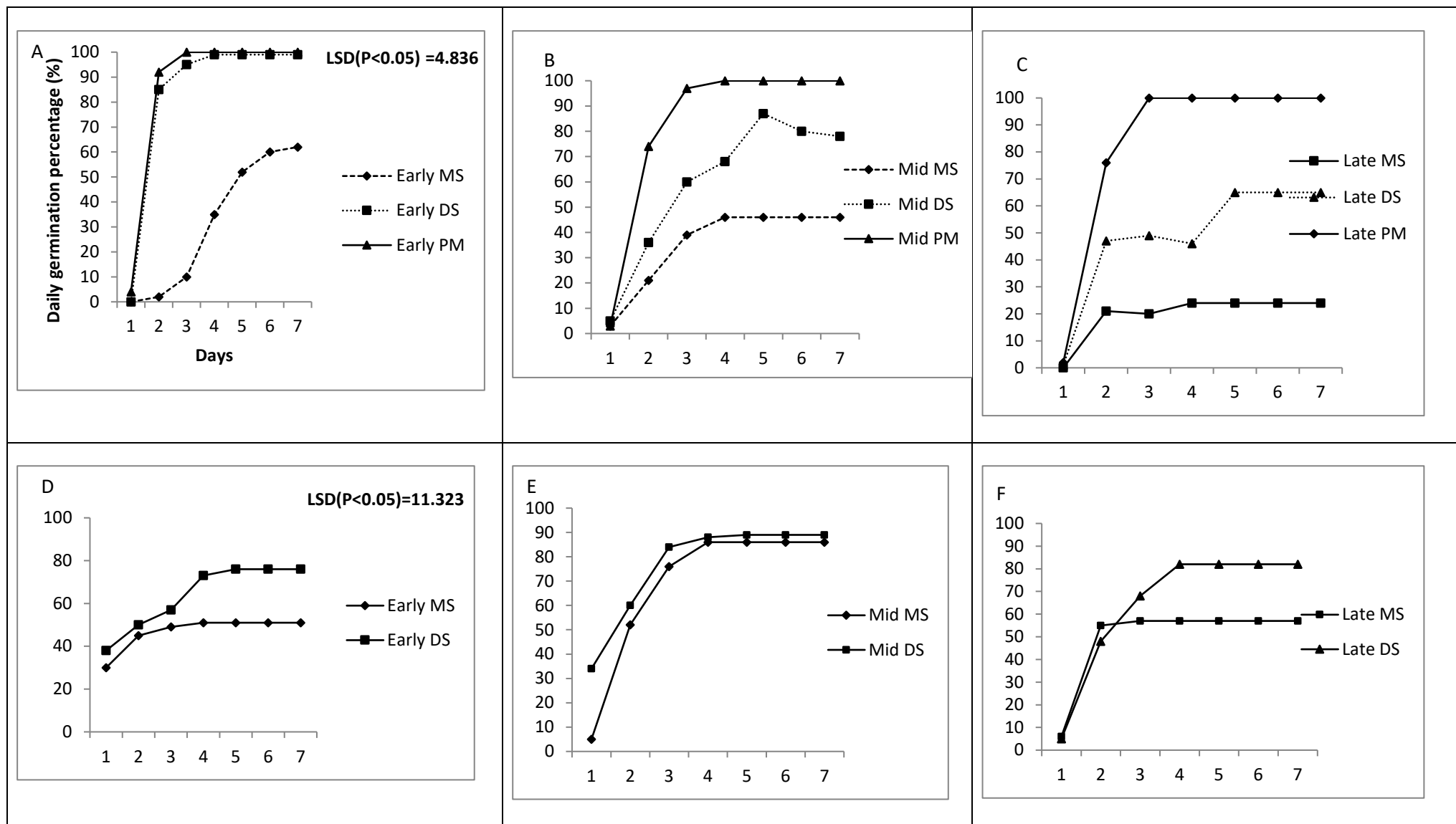


Figure 5.2: Daily germination percentage A and D = early, B and E = mid and C and F = late planting for seeds at different harvesting stages (MS = milk stage, DS = dent stage and PM = physiological maturity) during 2014/15 and 2015/16 seasons respectively.

Highly significant variation ($P < 0.001$) was observed in the interaction of planting date \times harvesting stage with regards to final germination (FG) during 2014/15 season (Table 5.2). The final germination of seeds from dent stage and physiological maturity under early and late planting performed similarly while the least FG were recorded at milk stage in each planting date. During 2015/16 season, highly significant differences ($P < 0.001$) only occurred among the harvesting stages but no significant differences ($P > 0.05$) was observed in the interaction of planting date \times harvesting stages (Table 5.2). However, the highest final germination occurred in seeds from dent stage under mid planting date while the lowest final germination was in seed lot from milk stage under early planting. Overall, harvesting stage had highly significant influence ($P < 0.001$) on the daily and final germination in both seasons. However, planting dates and the interaction of planting date \times harvesting stage were not significantly influenced ($P > 0.05$) daily and final germination (Table 5.2).

Table 5.2: Germination and vigour indices for seeds under different harvesting stages and planting dates during 2014/15 (1st year) and 2015/16 seasons (2nd year)

Planting dates (P)	Harvesting stages (H)	FG (%)		VI		MGT (days)		GVI		EC (μ S/cm/g)	
		1st year	2 nd year	1st year	2 nd year	1st year	2 nd year	1st year	2 nd year	1st year	2 nd year
Early	Milk stage	64.00b	58.00a	1213ab	956.00a	4.28d	2.12bc	11.64b	9.65ab	975.40a	1651b
	Dent Stage	99.00d	83.00a	3422e	2348d	2.18ab	1.68a	37.34f	13.23c	224.30a	749a
	Physiological maturity	100.00d	-	3512e	-	2.04a	-	39.82g	-	84.90a	-
Mid	Milk stage	38.00a	66.50a	1512bc	1504b	2.57bc	2.42cd	15.01c	9.93bc	911.30a	1155ab
	Dent Stage	78.00c	86.00a	2112d	2336d	2.83c	1.93ab	24.94e	13.62c	223.80a	529a
	Physiological maturity	100.00d	-	3250e	-	2.26ab	-	37.07f	-	67.20aa	-
Late	Milk stage	76.00c	62.00a	718a	1100a	2.44abc	2.54d	8.85a	8.35a	992.30a	3216c
	Dent Stage	96.00d	76.00a	1786cd	1790c	2.71c	1.97ab	21.36d	9.42ab	261.40a	944ab
	Physiological maturity	100.00d	-	2125d	-	2.22ab	-	37.32f	-	97.40a	-
P \times H		(P<0.001)	(P>0.05)	(P<0.05)	(P<0.05)	(P<0.001)	(P<0.05)	(P<0.001)	(P<0.05)	(P>0.05)	P<0.05)
(LSD _{P<0.05})		5.622	13.120	543.7	280.7	0.441	0.299	1.965	1.307	80.440	792.300
P ¹ F.test		(P>0.05)		(P<0.05)		(P>0.05)		(P<0.001)		(P<0.05)	
P ¹ LSD _(P<0.05)		8.357		255		0.327		1.277		287.30	
F.test		(P<0.001)		(P<0.001)		(P<0.05)		(P<0.001)		(P<0.001)	
H ¹ LSD _{P<0.05})		6.386		218		0.153		0.909		277.90	
Season (S ¹)		(P>0.05)		(P<0.001)		(P<0.001)		(P<0.001)		(P<0.001)	
S ¹ LSD _{P<0.05})		3.239		146		0.172		0.825		406.80	
P \times H ¹ F.test		(P>0.05)		(P<0.05)		(P<0.001)		(P<0.001)		(P<0.05)	
P \times H ¹ LSD _{P<0.05})		10.392		336		0.348		1.539		232.80	
P \times S \times H ¹		(P>0.05)		(P<0.05)		(P<0.001)		(P<0.001)		(P<0.05)	
LSD _{P<0.05})		11.475		406		0.435		2.017		550.80	

FG= final germination, VI= vigour index, MGT= mean germination time, GVI= germination velocity index, EC= electrical conductivity. 1 = Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons

Vigour indices

During 2014/15 season, the interaction of planting date \times harvesting stages had significant influence ($P < 0.001$) on the MGT and GVI. Seeds harvested at milk stage under early planting had the longest MGT (4.28 days) and lowest GVI (11.64), while the lowest MGT (2.04 days) and highest GVI (39.82) were recorded in physiological matured seeds under early planting. Mean comparisons of germination velocity index of seed lots harvested at physiological maturity under mid-planting were similar with its counterpart seeds from late-planting (Table 4.2). Similarly, the interaction of planting date \times harvesting stage had significant influence ($P < 0.05$) on the MGT and GVI of the seed lots during 2015/16 season. Seeds from milk stage under late planting gave the highest MGT (2.54 days) and the least GVI (8.35) while the least MGT (1.68 days) and highest GVI (13.23) occurred in seed lots harvested at dent stage under early and mid-planting dates respectively. Overall, there were highly significant differences ($P < 0.001$) among the planting dates, harvesting stages and their interaction in both seasons with regards to GVI and MGT. Seed lots obtained in each planting date during 2015/16 gave higher speed of germination than those seeds from 2014/15 season.

There was significant interaction ($P < 0.05$) between planting date \times harvesting stage for seedling vigour index obtained at both seasons. During 2014/15, the highest seedling VI was physiological mature seeds under mid planting and those seeds from dent stage and physiological maturity under early planting. The lowest VI was in seed lots harvested at milk stage under late planting. During 2015/16 season, the highest VI were at dent stage under early and mid-planting date and the lowest occurred in seed lots from milk stage under early and late planting. The interaction of planting date \times harvesting stage significantly influenced ($P < 0.001$) the vigour index (Table 5.2).

There was no significant interaction ($P > 0.05$) between planting date \times harvesting stages for electrical conductivity in seedlings from 2014/15 season. Though, physiological mature seeds under mid planting gave the least leachate while seed from milk stage in each of the planting date had the highest leachate. During 2015/16 season, the interaction of planting dates and harvesting stages significantly influenced ($P < 0.05$) the seedling electrical conductivity. Seeds from dent stage under early and mid-planting had the least leachate while the highest leachate was from milk stage under late planting. Overall, highly significant difference ($P < 0.001$) was observed in EC among harvesting stages and seasons. In addition, the interaction of planting date \times harvesting stages had significant influence ($P < 0.05$) on the EC (Table 6.2).

The interaction of planting date \times harvesting stage had no significant influence ($P > 0.05$) on the seedling root length during 2014/15 season. Though physiological mature seeds under early planting had the longest RL (25.75 cm) while seed from milk stage under late planting had the shortest RL (18.38 cm). However, during 2015/16 season, significant interactions ($P < 0.05$) of planting date \times harvesting stage was observed for RL. Overall, planting date, harvesting stages and their interaction significantly influenced ($P < 0.05$) the RL.

The interaction of planting date \times harvesting stage had no significant influence ($P > 0.05$) on the seedling shoot length at both seasons. Though increasing trend occurred from milk stage to physiological maturity in each planting date. Overall, harvesting stages had significant difference ($P < 0.001$) on the SL but planting dates had no significant difference ($P > 0.05$) on the SL. There was significant difference ($P < 0.05$) among all their interactions.

The interaction of planting date \times harvesting stage had significant influence ($P < 0.05$) on the seedling root: shoot ratio, fresh and dry mass in both seasons. Increasing trend in root: shoot ratio was observed in seeds from milk to physiological maturity stage in each planting date

across the season. During 2014/15 season, seeds lots harvested at physiological maturity under mid planting had the highest performances for FM and DM followed by its counterpart seeds from early planting. While, seeds obtained at milk stage under late planting had the lowest FM and DM. However, during 2015/16 seedling fresh mass obtained at dent stage for each planting dates were statistically similar (Table 5.3). Overall, significant differences were only observed among planting dates and harvesting stages while no significant interaction exist in their interactions with regards to R:S, but the interaction of planting date \times harvesting stages, significantly influenced the fresh and dry mass. There were decreasing trends in FM and DM of seedlings harvested from physiological maturity to milk stage.

Table 5.3: Germination vigour indices for seed lots from different harvesting stages and planting dates during 2014/15 91st year) and 2015/16 (2nd year)

Planting dates (P)	Harvesting stages (H)	RL (cm)		SL(cm)		RS		FM (g)		DM (g)	
		1st year	2 nd year	1st year	2 nd year	1st year	2 nd year	1st year	2 nd year	1st year	2 nd year
Early	Milk stage	12.38a	10.13a	6.62a	6.20a	1.00a	1.50a	6.48a	4.17b	2.18c	0.33a
	Dent Stage	22.00a	19.52c	9.38a	8.65a	1.53bc	2.27c	21.64de	7.22d	3.69de	0.97d
	Physiological maturity	25.75a	-	12.50a	-	2.56d	-	24.36ef	-	4.25e	-
Mid	Milk stage	11.62a	15.05b	9.00a	7.63a	1.01a	1.98bc	9.94b	5.26c	0.34a	0.52b
	Dent Stage	14.62a	18.38c	9.25a	8.98a	1.49abc	2.06bc	16.27c	7.52d	1.83bc	1.00d
	Physiological maturity	12.75a	-	11.25a	-	1.52bc	-	25.43f	-	3.81de	-
Late	Milk stage	10.88a	11.23a	7.25a	6.74a	1.24ab	1.77ab	4.95a	1.73a	0.97ab	0.47ab
	Dent Stage	12.75a	15.40b	8.38a	8.18a	1.47abc	1.88abc	16.75c	6.95d	1.27bc	0.71c
	Physiological maturity	21.25a	-	9.88a	-	1.90c	-	20.94d	-	3.18d	-
P × H		(P>0.05)	(P<0.05)	(P>0.05)	(P>0.05)	(P<0.05)	(P<0.05)	(P<0.05)	(P<0.001)	(P<0.001)	(P<0.05)
(LSD _{P<0.05})		4.643	2.470	2.521	1.442	0.501	0.431	2.941	0.778	0.932	0.159
F.test P ¹		(P<0.05)		(P>0.05)		(P<0.05)		(P>0.05)		(P<0.001)	
LSD _{P<0.05}		2.029		1.154		0.224		1.051		0.263	
F.test H ¹		(P<0.001)		(P<0.001)		(P<0.05)		(P<0.001)		(P<0.001)	
LSD _{P<0.05}		1.565		0.775		0.215		0.622		0.335	
Season (S ¹)		(P>0.05)		(P<0.05)		(P>0.05)		(P<0.001)		(P<0.001)	
LSD _{P<0.05}		1.764		0.860		0.280		0.750		0.251	
P × H ¹		(P<0.05)		(P<0.05)		(P>0.05)		(P<0.05)		(P<0.05)	
LSD _(P<0.05)		2.534		1.358		0.315		1.184		0.453	
P × S × H ¹		(P>0.05)		(P<0.05)		(P>0.05)		(P<0.001)		(P<0.05)	
LSD _(P<0.05)		3.821		1.935		0.560		1.684		0.602	

RL = root length, SL= shoot length, R:S = root : shoot ratio, FM = fresh mass, DM = dry mass, 1 = Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons

Seed quality characteristics

There was highly significant interaction ($P < 0.001$) between planting date \times harvesting stages for thousand seed weight obtained in 2014/15 season. The heaviest TSW was from seed lot harvested at physiological maturity under early and mid-planting. There were no statistical differences in TSW obtained at milk stage at each planting date though seed lots harvested at milk stage under late planting had the least TSW. During 2015/16 season, seed lots from dent stage under mid plant had the heaviest TSW followed by seed from dent stage under early planting while seeds from milk stage under late planting had the lowest TSW. Overall, highly significant difference ($P < 0.001$) was observed in TSW among the planting dates and harvesting stages. The interaction of planting date \times harvesting stages had significant influence ($P < 0.05$) on TSW (Table 5.4).

The interaction of planting date \times harvesting stage significantly influenced ($P < 0.05$) seed moisture content during 2014/15 season. The seed moisture content declined from milk stage to physiological maturity in each planting date. However, there was no significant difference in interaction of planting date \times harvesting stage but significant difference ($P > 0.05$) occurred in seed moisture content during 2015/16 season. (Table 5.4).

Table 5.4: vigour indices for seed lots from different harvesting stages and planting dates during 2014/15 (1st year) and 2015/16 (2nd year) planting season

Planting dates (P)	Harvesting stages (H)	TSW (g)		SMC (%)	
		1st year	2 nd year	1st year	2 nd year
Early	Milk stage	269.20a	331.50a	79.20e	79.84a
	Dent Stage	619.00c	563.50c	56.85bc	57.27a
	Physiological maturity	705.90d	-	21.85a	-
Mid	Milk stage	260.20a	402.50b	71.59d	80.70a
	Dent Stage	670.30cd	647.80d	53.94b	54.47a
	Physiological maturity	684.40d	-	24.17a	-
Late	Milk stage	221.40a	352.00a	71.54d	79.58a
	Dent Stage	428.00b	407.30b	62.37c	59.00a
	Physiological maturity	408.50b	-	22.24a	-
F.test $P \times H$		($P < 0.001$)	($P < 0.05$)	($P < 0.05$)	($P > 0.05$)
$P \times H$ (LSD $P < 0.05$)		60.460	49.940	7.000	5.701
F.test		($P < 0.001$)		($P < 0.05$)	
P^1 LSD $P < 0.05$)		38.92		5.264	
F.test		($P < 0.001$)		($P < 0.001$)	
H^1 LSD $P < 0.05$)		19.21		2.024	
F.test		($P < 0.001$)		($P < 0.05$)	
Season (S^1) LSD $P < 0.05$)		21.24		2.351	
F.test		($P < 0.001$)		($P > 0.05$)	
$P \times H^1$		41.88		5.451	
F.test		($P > 0.05$)		($P > 0.05$)	
$P \times S \times H^1$		53.13		6.451	

TSW= thousand seed weight and SMC= seed moisture content. 1 = Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons

Discussion

The knowledge of seed physiology and development during different environmental conditions will help ensure high seed quality in terms of germination and vigour during the forecast climate change (Bita and Gerats 2013). Studies have shown that seed harvested prior to attainment of physiological maturity are under developed having less food reserve as compared to those seed harvested at physiological maturity (Alabi, et al. 2005, Jacob Junior, et al. 2014). However, the contribution of environmental factors experienced during seed development might have strong influence on the viability and vigour of the seed at any stages of its development.

This study observed that environmental variation (different planting dates) during seed development and maturation caused variation in the germination percentage of the progeny seeds harvested at each planting date. Although, the highest germination percentage were attained at physiological maturity irrespective of the planting dates. It might be due to physiologically mature seeds contain higher food storage and displayed better viability than immature seeds (Marcos Filho 2015). Nevertheless, progeny seed from dent stage under early and mid-planting in warmer and drier seasons respectively showed high germination percentage promises by performing at par with physiological mature seeds. The favourable weather conditions might have contributed to it, allowing maximum accumulation of photosynthates. The high reduction in germination percentage in progeny seed from milk stage irrespective of their planting dates might be due to presence of more number of immature and unfilled seed. This indicated that stages of maturity at harvest had greater impact on progeny seed germinability than variation in weather conditions during their development. This study agreed with Todoran (2014) who observed that stages of seed maturity at harvest influenced germination percentage and vigour of the seedlings.

The ability of physiological mature seeds from early planting during warmer (2014/15) season to have reduced mean germination time and high germination velocity index might be attributed to higher food reserve. It continue to supply enzymatic activities during germination with energy coupled with optimal growing conditions received. Seeds planted earlier during warmer season received adequate rainfall and temperature which was suitable for seed development compared to those seed planted lately which experienced low temperature and rainfall during their seed maturation. Thus, diminished the progeny seed quality. Du Plessis (2003) explained that annual rainfall of 350 - 450 mm is required to produce maize seed yield of 3 tonnes per hectare under rain-fed conditions. de Carvalho et al., (1999) reported that timing of any unfavourable temperature regime during the parent's life cycle affects seed germinability of the progeny. This study showed that extreme low in temperature during seed maturation accelerated seed development at the expense of seed quality. Our findings support earlier report that maize respond differently to environment of production (Tekrony and Hunter 1995). This result was contrary to Samarah and Al-Issa (2006) who reported that planting date had no effect on seed quality of barley under semi-arid conditions. However, this finding agreed with Woltz et al., (2006) who suggested that seed would still have higher germination and vigour if harvested earlier before the extreme environmental conditions than exposing it to the stress.

The increase in seedlings vigour index of seeds from dent stage and physiological mature seeds from early and mid-planting dates might be due to earlier initiation of shoot and root apical meristem during maturation. Faria et al., (2002) found that higher germination rate and physiological quality in seed harvested at 50% solid endosperm which was equivalent of 41 days after silking. In addition, during dent stage (R₅) of development some of the essential seed component and physiological attributes might have been attained which enhanced the

seedlings vigour. Since seed accumulates most of its dry weight during dough development (Zečević et al., 2006). This facilitated seedling viability and vigour, thus seed harvested at dent stage exhibited some level of vigour though maximum seed vigour was attained at physiological maturity. There were little differences in vigour index exhibited at dent stage and physiological maturity, indicating that commensurable amount of vigour was acquired at dent stage under optimal planting conditions (2014/15 season).

Progeny seeds from physiological maturity under extreme weather conditions (late planting) expressed poor germination and vigour especially in the seedling length, fresh and dry mass. Seeds from dent stage under early planting performed similarly in seedlings shoot length and higher in root length than physiological mature seeds from mid and late planting during warm season. Seedling length is one of the criteria for determining vigorous seedlings because higher seedling length could produce vigorous root system (Farhadi et al., 2014). This study observed that physiologically matured seeds under favourable environmental conditions had the highest seedling length and seeds from dent stage performed second best.

The increase in root: shoot ratios of seedlings harvested at physiological maturity and dent stage under early and mid-planting could be attributed to increase in maternal shoot net assimilation rates under favourable weather conditions resulting in large food reserve in the kernel (Bita and Gerats 2013). This might have helped the progeny seeds to supply more energy to the shoot and root apical during germination. Therefore, progeny seed harvested under suitable weather conditions gave higher root: shoot ratios than progeny seed lots harvested under harsh weather conditions.

The linear decline in seeds moisture content and increase in thousand seed weight from milk stage to physiological maturity could be attributed to the gradual increase in accumulation

of photosynthates into the kernel. In an experiment conducted by Hunter et al., (1991) on stages of maize seed maturity at harvest, they reported that maximum seed weight occurred, as the seed were physiologically mature. Though, their emphasis was not on the environmental conditions during maturation. This study showed that early harvest seed lots (milk stage) had the lowest seed germination and vigour indices because of its high percentage of immature seeds, moisture content and low thousand-seed weight irrespective of planting conditions. Stage of seed maturity and maternal environmental conditions during growth and development significantly influenced its quality (Ellis et al., 1993). Though seed at early developmental stage were capable of germination, could be due to embryo maturity occurred earlier during development. However, their germination capacity was very low compared with physiologically matured seeds.

High leachate in seeds harvested at milk stage and from late planting might be due to its low seed vigour as expressed through its lower thousand seed weight, seedling fresh and dry mass, germination percentage and vigour index. Since, seed maturation during late planting coincided with drop in atmospheric temperature and rainfall. This study concurred with Farhadi, et al. (2014) who explained that stressful environmental conditions caused cell membrane of seeds to become thin and lead to more leakage of electrolytes. Hampton, et al. (2013) explained that temperature stress before seeds reach physiological maturity could reduce germination by inhibiting the ability of the plant to supply assimilates necessary to synthesize the storage compounds required for germination. Low atmospheric temperature during late planting, might have limited the mobility of nutrients in the soil, reduced the root growth, and thereby limited availability of nutrients to the maternal plant, and consequently lead to lower thousand seed weight and vigour. This study confirmed the observation of Bitu and Gerats (2013) who explained that the patterns of nutrient accumulation in kernel are greatly

affected by temperature, moisture, and other conditions that alter biological activity. Decrease in seed moisture content, increase seed weight and germination percentage comes with delay in harvesting. However, late planting which usually fall within unfavourable environmental conditions negatively affects the progeny seed viability and vigour even when allowed to attain maximum maturity.

Conclusion

To minimize negative effect of environmental stress on maize seed quality the understanding of the interaction that existed between planting dates and harvesting stages may play a major role. The environmental conditions during maturation as showed by the high seedling germination of physiologically mature seeds under early planting was an indication of superiority of physiologically mature seed over immature one and favourable weather conditions over harsh ones. Delay in planting reduced seed quality performance in maize while early and mid-planting tend to experience optimum atmospheric temperature and rainfall for seed production in warmer and drier season respectively. This study showed that high seed quality in maize could be attained by planting early during warmer season but mid planting would give the maximum seed quality during drier season or drought period. In addition, stage of seed maturation during harvesting is an important decision to be considered before harvesting especially during extreme weather conditions. Depending on the weather forecast, early planting (November) favoured the attainment of high seed quality of SC701 maize in warmer season while mid planting date (December) would give the best seed quality in drier season. Progeny seeds from dent stage under favourable weather conditions outperformed those seeds that attained physiological maturity under adverse weather conditions in terms of seed quality. Therefore, harvesting at dent stage under favourable planting conditions would

give commensurable high seed quality than those seeds allowed to reach physiological maturity under extreme weather conditions.

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CHAPTER 6

Response of maize seed quality to varying planting date and soil fertility under rain fed condition¹

¹In preparation for submission to Journal of Soil Science and Plant Nutrition

Abstract

Variation in environmental conditions and soil fertility status may affect maize grown in semi-arid regions, where extreme temperature and rainfall constantly occur especially during late crop development and maturation. The aim of this study was to evaluate the interactive effect of planting dates and soil fertility levels on seed germination and vigour of a commonly grown southern Africa maize hybrid (SC701). A split plot experiment in randomized complete block design with four replicates was conducted in 2014/15 and 2015/16 seasons at the research farm of the University of KwaZulu-Natal. Seeds were harvested at physiological maturity. Subsequently, the quality of seed lots was determined through laboratory germination test and electrical conductance. Germination percentage, speed of germination, thousand seed weight fresh and dry mass of the seedling were significantly enhanced ($P < 0.05$) but mean germination time and electrical conductivity of seed leachate were significantly reduced ($P < 0.05$) with increasing fertility level at each planting date. Though, maximum seed quality of maize was attained at the optimal fertilized trial under early planting in warmer season and under mid planting date in drier season. Differences in seedling fresh and dry mass were attributed to variation in seed weight and water content which was enhanced by fertilization under favourable weather conditions. It was concluded that maximum seed quality could be achieved by optimal fertilization under favourable weather condition and fertilization under extreme weather condition has little or no positive effect on maize seed quality.

Keywords: Fertilizer, germination, planting, seedlings, vigour

Introduction

The use of adaptive management practices such as variation in planting date and improving soil fertility status in crop production are of great importance. Since, environmental factors greatly influence plant growth and development, particularly in semi-arid regions. Production of high maize seed quality requires adequate soil nutrients and favourable environmental conditions. Maize (*Zea mays* L.) is the most important cereal in the world, over 90% of the population in Southern Africa depend on maize as their staple diet and grown in a range of agro ecological environments (Admire and Shokora 2014). Maize is a high soil nutrient exhaustive crop; its productivity is largely dependent on its nutrient requirement and environmental conditions. However, majority of agricultural soils in South Africa are acidic, low in nitrogen, phosphorus, cation exchange capacity and organic matter content (Mandiringana et al., 2005). Wambugu et al., (2012) reported that fertilizer application increases seed vigour, viability and yield in maize. Variation in planting dates and improving the soil fertility through application of fertilizer might increase maize yield, quality and minimise risks under adverse weather conditions. However, it is not known whether improving soil fertility through fertilizer application would still improve seed quality under different environmental conditions.

Seed quality is a complex trait, which comprises viability, and vigour attributes that enables the emergence and establishment of normal seedlings under a wide range of environments (Khan et al., 2012). Studies showed that extreme temperatures have strong negative relationship on germination rate, emergence time, and germination uniformity (Ahmad et al., 2014, Hampton et al., 2013). However, role of improving soil fertility during extreme weather conditions with regards to seed quality is not well documented. The severity of extreme temperatures and erratic rainfall associated with seasonal changes might influence

the release of nutrients from soil and impair the rate of nutrient uptake and accumulation of photosynthates, which might have resultant effect on the seed quality produced.

Seed producers are faced with the daunting task of improving soil fertility under varying weather conditions to achieve higher yield and quality. The possibility of producing high quality maize seed during current variation in weather conditions through fertilizer application needs more studies. Therefore, this chapter focused on the interactive effect of different planting dates and soil fertility level on the progeny maize seed quality under small scale farming conditions. It was hypothesized that maintaining the soil fertility through fertilizer application might improve the quality of progeny seed during extreme weather conditions.

Materials and methods

Site description, experimental design and layout section, data collection, weather data, crop phenology and field layout and experimental design used were similar and has been described in chapter 5, materials and method section.

Crop management

Land preparation involved ploughing, disking and rotovating to achieve fine tilth for good seed to soil contact. The herbicides 2-chloro- 2-(6-diethyl-N-(methoxymethyl) acetanilide (alachlor) was broadcast pre-emergence at rates of 2.8 kg/ha. Prior to planting in 2014/15 and 2015/16 seasons, soil sampling was collected from top soil (0-20 cm) randomly and analysed for selected physicochemical properties (Table 4.1). Based on soil fertility results, fertility treatments consisted of nitrogen (N) and phosphorus (P) since the soil was not deficient of potassium (K). The fertilizer treatment consists of control (0 N kg/ha, 0 P kg/ha), minimal (100 N kg/ha, 10 P kg/ha) and Optimal (200 N kg/ha, 20 P kg/ha) fertilizer respectively for urea (N) and triple super phosphate granule fertilizer (50% P). For N fertilizer, each level was split into

two equal parts (half was applied at planting and other half at 8 weeks after planting). Weeds were controlled manually by hand hoeing. Pesticide was sprayed to control the infestation of insect pest.

Table 6. 1: Physicochemical properties of soil at (0 - 20 cm) before setting up the experiments at Ukulinga site in 2014/15 and 2015/16 planting seasons

Fertility levels	Density (mg/L)	P (mg/L)	K (mg/L)	N (%)	Ca (mg/L)	PH (KCl)	Mg (mg/L)	Mn (mg/L)	Cu (mg/ L)	Exch. Acidity (C mol /L)	Total cations mol/L)	(C Clay (%)	*Soil texture	Organic Carbon (%)
(2014/15) season	1.18	38	424	0.23	1739	4.45	581	27	10.8	0.18	14.72	31	Clayey loam	2.30
(2015/16) Early control	1.11	30	379	0.23	1938	4.80	681	23	7.0	0.11	16.40	31	Clayey loam	2.20
Minimal	1.12	30	453	0.23	1886	4.86	683	38	7.6	0.11	16.30	32	Clayey loam	2.30
Optimal	1.17	36	492	0.22	1799	4.60	687	27	9.97	0.11	15.79	31	Clayey loam	2.30
Mid control	1.13	33	391	0.22	1813	4.82	660	30	8.6	0.14	15.62	29	Clayey loam	2.20
Minimal	1.14	39	407	0.21	1802	4.76	652	28	8.9	0.14	15.54	30	Clayey loam	2.10
Optimal	1.11	45.3	453	0.20	1745	4.65	655	31	9.2	0.16	15.41	31	Clayey loam	2.10
Late control	1.14	44.3	473	0.23	1760	4.73	658	22	8.3	0.19	15.60	31	Clayey loam	2.20
Minimal	1.14	50.3	548	0.23	1760	4.74	665	41	9.5	0.09	15.75	32	Clayey loam	2.30
Optimal	1.14	39.7	462	0.20	1795	4.70	665	38	8.1	0.23	15.90	31	Clayey loam	2.00

Exch. Acidity = Exchangeable acidity

Seed Harvest

Maize ears were harvested at physiological maturity stage (R_6) in each planting dates except in mid and late planting dates of 2015/16 season where the dent stage of the maize was harvested due to the invasion of wild pigs. At each harvest six ears were randomly selected in each plot and first ear from the top of the plant was harvested by hand.

The seed moisture content (SMC) was determined by wet weight basis.

Thousand-seed weight (TSW) was determined by counting hundred seed from each treatment and multiplying by 10. Harvested ears were placed on benches in the glasshouse under dry conditions and allowed to dry to < 12% moisture content. Dry seed from the middle and basal sections of maize ears were threshed by hand and stored at 4°C in the cold room until further analysis.

Electrical conductivity, Laboratory standard germination test and description of statistical analysis were the same as the previous chapter

Results

Weather data

The weather data obtained for 2014/2015 planting season was consistent with the long-time weather data for the site. However, weather data for 2015/16 deviated marginally with an average temperature increase of 2.3°C (November to March) from the observed annual mean

maximum temperatures for the months. Comparing the two seasons, maximum and minimum temperatures were higher in 2015/16 (28.1°C and 15.6°C) than 2014/15 (24.9°C and 14.9°C respectively) which were not in uniformity with the long-term maximum and minimum temperatures of 25.6°C and 16.9°C (Fig. 6.1). This might have resulted in longer heat units' accumulation for early-planted maize and quickens in seed development during 2015/2016 as compared with 2014/15 season.

Comparing the rainfall received during the early, mid and late planting dates in the two seasons, 2014/15 season (407.9 mm, 371.6 mm and 267.2 mm) received more distribution of rain than 2015/16 (444.8 mm, 360.7 mm and 208.4 mm) respectively (Fig 1). Almost 80% of rainfall received during 2015/16 was received from January- March while the rest were sparingly distributed. In addition, there were more days of no rainfall during the seed developmental stage of the crop in 2015/16 than 2014/15 season (Fig. 6.1). The observed results suggested the possibility of intermittent water stress was higher in 2014/15 than 2015/16 season.

Early and mid-planting experienced adequate precipitation and temperature, which was most suitable for seed development compare to late planting. Seed planted lately experienced low minimum temperature and rainfall during late seed development, there were days where the average temperature was below 16°C. The total rainfall received during late planting in the first and second seasons were far below the recommended water requirement for dry land maize production. The weather data indicated 2014/15 season as more conducive for seed development than 2015/16 season though incidences of hail storms were more frequent during 2014/15 season than during 2015/16 (Fig. 6.1).

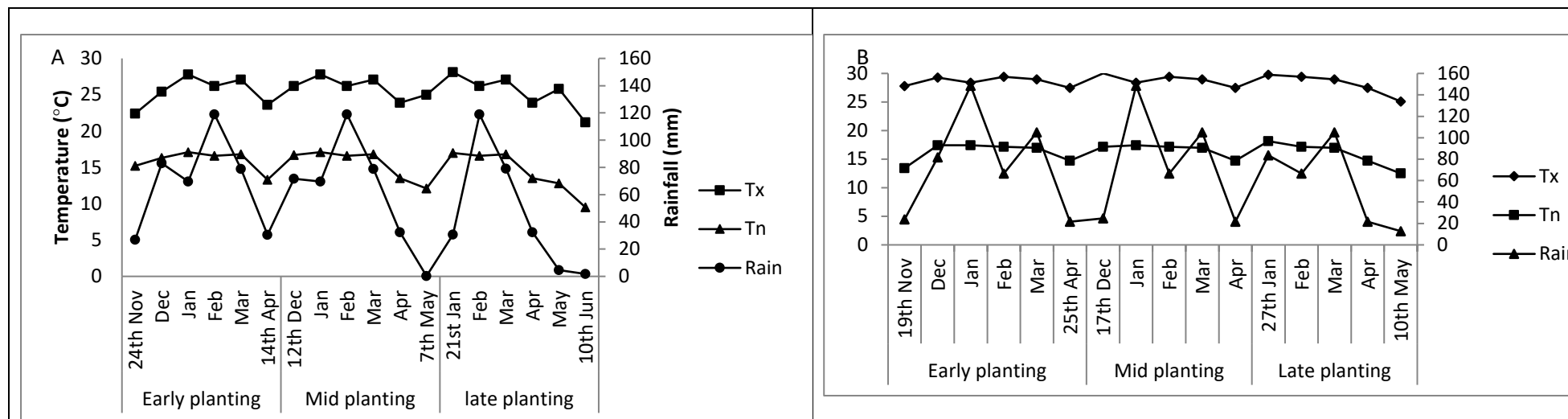


Figure 6.1: Variation in monthly rainfall (rain) and maximum (T_x) and minimum (T_n) temperatures ($^{\circ}\text{C}$) recorded during A = 2014/15 and B = 2015/16 planting seasons at Ukulinga, Pietermaritzburg South Africa

Crop phenology

Time to reach 50% tasselling and 50% silking were significantly affected ($P < 0.05$) by the interactions of planting dates \times fertility levels (Table 6.2). During 2014/15 season, application of fertilizer prolonged the time to accumulate heat units for tasselling and silking at different planting dates. This was contrary in 2015/16 season, where increased rates of fertilizer application shortened the accumulated heat units required for tasselling and silking except during mid planting where fertilizer application increased the time required to accumulate heat units (Table 6.2). It was observed that under water deficit conditions, application of fertilizer shortened the time required to accumulate heat unit for flowering as observed during 2015/16 season especially under late planting. However, reverse conditions occurred during favourable weather conditions (2014/15 season).

Table 6.2: Phenological stages of SC701 maize grown under different planting dates and fertility levels during the 2014/15 and 2015/16 seasons. Values in the same column sharing the same superscript letter are not significantly different ($P < 0.05$).

Planting dates (P)	Fertility levels (F)	TTT (°cd)		TTS (°cd)	
		2014/15	2015/16	2014/15	2015/16
Early	Control	846.10b	951.00c	918.00bc	1011.90e
	Minimal	881.80c	899.00bc	958.40de	966.90d
	Optimal	893.40cd	828.00b	972.40e	961.90d
Mid	Control	822.00ab	825.00b	896.30ab	889.10b
	Minimal	891.20cd	829.00b	939.90cd	895.90b
	Optimal	908.40d	877.00bc	976.00e	927.40c
Late	Control	810.90a	888.00bc	884.30a	975.50d
	Minimal	820.90ab	640.00a	891.70a	836.10a
	Optimal	873.60c	681.00a	920.10c	839.30a
LSD values $P \times F$		25.940	103.700	22.520	28.470
LSD values P^1		23.460		6.130	
F.test		$P < 0.05$		$P < 0.05$	
LSD($P < 0.05$) F^1		34.980		10.050	
F.test		$P > 0.05$		$P < 0.05$	
LSD values Seasons (S)		26.250		8.640	
F.test		$P > 0.05$		$P > 0.05$	
LSD values $P \times F^1$		52.640		14.960	
F.test		$P < 0.05$		$P < 0.001$	
LSD values $P \times F \times S^1$		75.410		23.290	
F.test		$P < 0.05$			

1 = Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons for the three planting dates TTT and TTS = time to reach 50% tasselling and silking respectively and 1 = Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons for the three planting dates

Germination percentage

During 2014/15 season, the interaction of planting date \times fertility level significantly influenced ($P < 0.001$) daily germination percentage (Fig 6.2). Days to attain maximum germination percentage were faster among seed lots with optimal and minimal fertilization. It occurred within 3 days while seeds with no fertilizer application took up to 4 days to attain maximum germination percentage under early planting. Similar trend was observed among seed lots from mid-planting date, but there was no difference in the daily germination percentage of the seed lots under different fertilizer application in late planting (Fig.6.2).

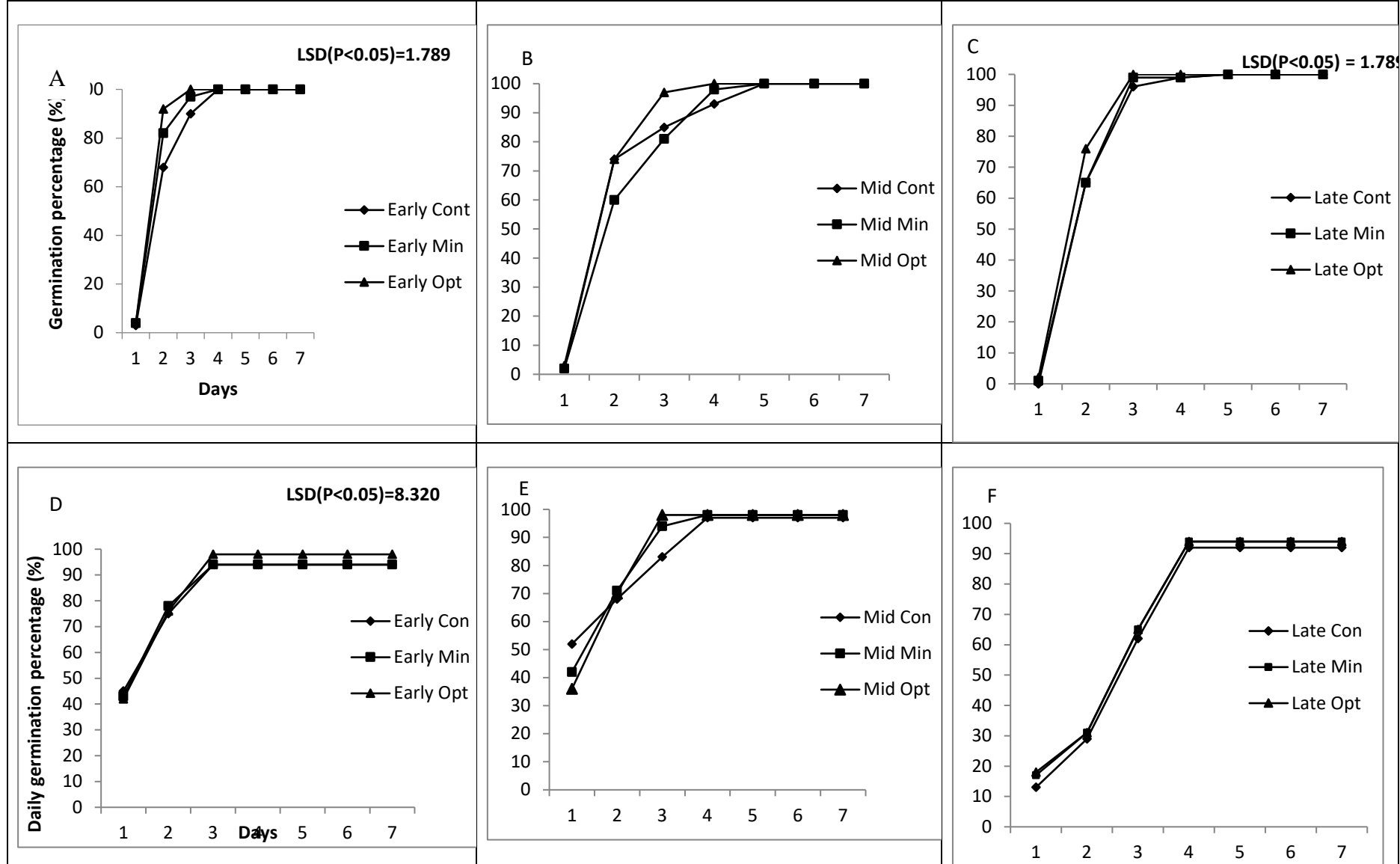


Figure 6.2: daily germination percentage under different fertility level A and D =early planting, B and E = mid planting and C and F = late planting during 2014/15 and 2015/16 seasons. Early Con = early planting without fertilizer, Early Min = early planting with minimal fertilizer application, Early Opt = early planting with optimal fertilizer application, Mid con = mid planting without fertilizer, Mid Min = mid planting with minimal fertilizer application, Mid Opt = Mid planting with optimal fertilizer application, late con = late planting without fertilizer, Late Min = late planting with minimal fertilizer application and Late Opt = late planting with optimal fertilizer application.

There was no significant difference ($P > 0.05$) between the interactions of planting date \times fertility level with regards to daily germination during 2015/16 season. Though seed lots from optimally fertilized had the highest DG under early planting while both seed lots from optimally and minimally fertilized trial performed similarly under mid and late planting dates. Overall, planting dates significantly affected ($P < 0.001$) the DG as well as fertility level. However, there was no significant difference ($P > 0.05$) in DG for seasons and their interactions.

The interaction of planting date \times fertility level was not significant ($P > 0.05$) with regards to final germination in both seasons. Though, maximum germination was attained among progeny seeds obtained from 2014/15 compared to 2015/16 season (Table 6.3). Overall, planting dates, fertility levels and the seasons significantly affected ($P < 0.05$) the final germination but there were no significant differences in their interactions.

During 2014/15 season, the interaction of planting date \times fertility level significantly influenced ($P < 0.05$) seedling vigour index. The highest VI occurred in seedling with optimal fertilization under early planting (3625) while the least VI was from seedling without fertilization under late planting. Similarly, significant interaction existed between planting date \times fertility level for VI during 2015/16 season. The highest VI was observed among seedlings from optimal fertilized trial under early planting (3033) and mid planting (3098) while the least VI was from seedling without fertilization under late planting (1950). Progeny seed from 2014/15 exhibited higher seedling VI compared to those seeds from 2015/16 season. Overall, the fertility levels, season and interaction of planting date \times fertility level significantly affected ($P < 0.05$) VI. In addition, planting date strongly influenced ($P < 0.001$) VI (Table 6.3).

Vigour indices

The interaction of planting date \times fertility level significantly affected ($P < 0.05$) seedling mean germination time during 2014/15 season. Reduction in mean germination time was observed among progeny seeds obtained from optimally fertilized trial under early planting (2.04 days), while the longest mean germination time occurred among seeds without fertilizer application under late (2.40 days) and mid planting dates (2.46 days). However, there was no significant difference ($P > 0.05$) in the interaction of planting date \times fertility level for seedling mean germination time during 2015/16 season. Though, reduced MGT occurred among minimally fertilized seeds under early planting (1.67 days) and the longest MGT was among optimally fertilized seeds under late planting date (2.78 days). Overall, highly significant interaction ($P < 0.001$) occurred among the planting dates and seasons for MGT. In addition, fertility level significantly influenced ($P < 0.05$) the seedling MGT but there was no significant difference among their interactions (Table 6.3).

The interaction of planting date \times fertility level significantly influenced ($P < 0.05$) GVI during 2014/15 season. The highest GVI was observed among progeny seeds obtained from optimal fertilized trial under early (38.32) and late planting (37.32) while the least GVI was among minimal fertilized seed from mid-planting date (33.61). However, no significant difference ($P > 0.05$) occurred between interactions of planting date \times fertility level for GVI during 2015/16 season. Though, the highest GVI was observed among progeny seeds obtained from optimal (16.58) and no fertilized (16.58) trial under early planting while the least GVI was among no fertilized seed from late planting (9.88). Overall, the interaction of planting date \times fertility level significantly influenced ($P < 0.05$) GVI (Table 4.3).

Significant difference occurred ($P < 0.05$) between the interactions of planting date \times fertility level with regards to electrical conductivity of the seed leachate in both season. During 2014/15 season, the seed lots with the lowest leachate (79.90 $\mu\text{mol/g}$) were from optimal fertilized trial under early planting and seed lots from minimally (85.00) and optimally fertilized (79.70

μmol/g) trial under mid planting. The highest leachate was recorded among no fertilized seed lots under late planting (142.60). During 2015/16 season, the lowest leachate occurred among seeds with optimal fertilized trials under mid planting (364.00 μmol/g) while the highest was recorded among no fertilized seeds under late planting (1077.00 μmol/g). Overall, highly significant differences ($P < 0.001$) in electrical conductivity of seed leachate occurred among the planting dates, fertility levels and seasons. The interaction of planting date \times fertility level \times season was significantly different ($P < 0.05$) with regards to electrical conductance of the seed leachate.

Table 6.3: Interactive effect of planting date and fertility level on vigour and vigour indices of SC701 maize hybrid during 2014/15 (1st year) and 2015/16 (2nd year) season

Fertility levels		FG		VI		MGT		GVI		EC	
Planting dates		1st year	2 nd year	1st year	2 nd year	1st year	2 nd year	1st year	2 nd year	1st year	2 nd year
Early	Control	99.50a	94.00a	2561bc	2013ab	2.39d	1.87a	35.74bc	16.58a	132.00de	530.00b
	Minimal	99.50a	94.00a	3271de	2697c	2.17b	1.67a	38.32d	16.46a	102.10b	434.00ab
	Optimal	100.00a	98.00a	3625e	3033d	2.04a	1.69a	39.82e	16.58a	79.90a	449.00ab
Mid	Control	100.00a	97.00a	2437ab	2577c	2.46e	1.98a	35.38b	13.53a	113.50c	461.00ab
	Minimal	99.50a	98.00a	2961cd	2621c	2.26d	1.75a	33.61a	14.56a	85.00a	391.00ab
	Optimal	99.50a	98.00a	3209d	3098d	2.59bc	1.70a	37.07cd	16.16a	79.70a	364.00a
Late	Control	100.00a	92.00a	2132a	1950a	2.40d	2.76a	35.05ab	9.88a	142.60e	1077.00d
	Minimal	99.50a	94.00a	2358ab	2280b	2.36cd	2.75a	35.55b	10.65a	129.70d	695.00c
	Optimal	100.00a	94.00a	2119a	2223ab	2.22b	2.78a	37.32d	10.77a	98.60b	687.00c
P × F		(P>0.05)	(P>0.05)	(P<0.001)	(P<0.05)	(P<0.05)	(P>0.05)	(P<0.05)	(P>0.05)	(P<0.05)	(P<0.05)
(LSD _{P<0.05})		1.152	5.200	407.900	279.800	0.125	0.181	1.516	1.936	111.040	145.500
F.test		(P<0.001)		(P<0.05)		(P<0.001)		(P<0.001)		(P<0.001)	
P ¹ LSD _{P<0.05})		2.719		206.2		0.117		1.017		65.100	
F.test		(P<0.05)		(P<0.001)		(P<0.05)		(P<0.001)		(P<0.001)	
F ¹ LSD _{P<0.05})		2.101		146.1		0.148		0.583		55.200	
F.test		(P<0.001)		(P<0.05)		(P<0.001)		(P<0.001)		(P<0.001)	
Season(S ¹)		1.894		138.9		0.100		0.576		94.500	
LSD _{P<0.05})											
F.test		(P>0.05)		(P<0.05)		(P>0.05)		(P<0.05)		(P>0.05)	
P × F ¹		3.730		269.5		0.229		1.206		42.100	
F.test		(P>0.05)		(P>0.05)		(P>0.05)		(P>0.05)		(P<0.05)	
P × S × F ¹		5.343		388.8		0.305		1.666		126.000	

FG = final germination, VI = vigour index, MGT = mean germination time, GVI = germination velocity index and EC = electrical conductance of the leachate and 1 = Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons for the three planting dates

The interaction of planting date \times fertility level significantly influenced ($P < 0.05$) shoot length but no significant difference ($P > 0.05$) was observed for root length during 2014/15 season. The seeds from optimal fertilized trial under early planting gave the highest seedling RL (22.50 cm) and SL (11.75 cm). The lowest RL (13.70 cm) and SL (7.19 cm) occurred in no fertilized and optimal fertilized seeds from late planting respectively. During 2015/16, interaction of planting date \times fertility level significantly influenced ($P < 0.05$) the seedling root and shoot length. Optimal fertilized seed from mid-planting gave the highest RL (22.07 cm) and the least RL occurred among seedling without fertilizer application under late planting (12.48 cm). Also, seedlings from optimal fertilized trials under early and mid-planting performed similarly in shoot length (9.42 cm and 9.54 cm) while the least was observed among seedling from optimal fertilized trial under late planting. Overall, significant interaction occurred among the planting dates and seasons for root and shoot length. In addition, the fertility level significantly influenced ($P < 0.001$) the RL. However, there were no significant difference ($P > 0.05$) among their interaction for RL and SL (Table 6.4).

The root: shoot ratio was not significantly affected ($P > 0.05$) by the interaction of planting date \times fertility level in both seasons. It was observed that R: S obtained in seedling from 2015/16 was higher than those obtained in 2014/15 season. Overall, significant differences existed among the planting dates, fertility levels, seasons and interaction of planting date \times fertility level.

The interaction of planting date \times fertility level significantly influenced ($P < 0.05$) seedling fresh and dry mass at both seasons. During 2014/15, the highest FM (25.43 g) and DM (3.91 g) was observed among progeny seeds obtained from optimally fertilized trial under early planting while the least FM (16.63 g) was observed among minimal fertilized seed and the least DM (1.64 g) occurred among seeds without fertilizer application under late planting date. During 2015/16, seedling fresh and dry mass from optimal fertilized seed under early and mid-planting had the

highest while the least was from seed with no fertilizer application under early planting (Table 6.4). Overall, the interaction of planting date \times fertility level significantly influenced fresh and dry mass.

Table 6.4: Interactive effect of planting date and fertility level on germination characteristics of SC701 maize hybrid during 2014/15 (1st year) and 2015/16 (2nd year)

season

Planting dates	Fertility levels	RL (cm)		SL(cm)		R:S		FM (g)
		1st year	2 nd year	1st year	2 nd year	1st year	2 nd year	1st year
Early	Control	16.75a	14.53ab	9.00bc	6.90a	1.87a	2.10a	21.4
	Minimal	21.76a	20.07de	11.12de	8.65cd	1.96a	2.36a	24.1
	Optimal	24.50a	21.50e	11.75e	9.42d	2.09a	2.28a	25.4
Mid	Control	16.25	18.13cd	8.12ab	8.40bc	2.02a	2.16a	18.8
	Minimal	19.75a	18.78d	10.00cd	7.97bc	1.99a	2.36a	22.9
	Optimal	22.50a	22.07e	11.25de	9.54d	1.89a	2.35a	24.3
Late	Control	13.70a	12.48a	7.62ab	8.70cd	1.88a	1.44a	12.9
	Minimal	15.00a	15.87bc	8.69abc	8.40bc	1.79a	1.89a	16.6
	Optimal	15.25a	16.12bc	7.19a	7.62ab	1.99a	2.13a	19.0
$P \times F$		($P > 0.05$)	($P < 0.05$)	($P < 0.05$)	($P < 0.05$)	($P > 0.05$)	($P > 0.05$)	($P < 0.05$)
(LSD $_{P < 0.05}$)		4.497	2.345	1.132	0.990	0.496	0.375	2.92
F.test		(P<0.001)		(P<0.05)		(P<0.05)		(P<0.05)
P^1 LSD $_{P < 0.05}$)		1.363		1.012		0.305		1.15
F.test		(P<0.001)		(P>0.05)		(P<0.001)		(P<0.001)
F^1 LSD $_{P < 0.05}$)		1.283		0.533		0.166		0.85
F.test		(P<0.05)		(P<0.001)		(P<0.001)		(P<0.001)
Season(S^1)		1.267		0.512		0.184		0.62
LSD $_{P < 0.05}$)								
F.test		(P<0.05)		(P<0.001)		(P<0.05)		(P<0.05)
$P \times F^1$		2.122		1.164		0.354		1.54
F.test		(P>0.05)		(P>0.05)		(P>0.05)		(P>0.05)
$P \times S \times F^1$		3.350		1.541		0.511		1.98

RL = seedling root length, SL = seedling shoot length, R:S = root: shoot ratio, FM = seedling fresh mass, DM = seedling dry mass, and 1 = Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons for the three planting dates

The interaction of planting date \times fertility level significantly influenced ($P < 0.05$) thousand seed weight obtained at both seasons. Thousand seed weight increases with increase in fertility level at early and mid-planting dates. Optimal fertilized seed under early planting had the heaviest TSW while the least TSW was observed among seeds without fertilizer application under late planting date in both seasons. There was no statistical difference in the TSW obtained at minimal and optimal fertilized trials under early and mid-planting dates. Though, increase in fertility level has no statistical differences among TSW obtained at late planting in both seasons. Overall, the planting dates, fertility levels, seasons and the interaction

of planting date \times fertility level significantly influenced TSW as well as the interaction of planting date \times fertility level \times season significantly influenced (Table 6.5)

The interaction of planting date \times fertility level had no significant effect ($P > 0.05$) on seed moisture content obtained at both seasons. In addition, no distinct trend was observed in the SMC among the planting dates and fertility levels in 2014/15 season. The only trend observed was in 2015/16 season where the SMC declined with application of fertilizer at each planting date. Overall, planting date, season, interaction of planting date \times fertility level and planting date \times fertility level \times season significantly influenced ($P < 0.05$) the seed moisture content but fertility had no significant effect on SMC (Table 6.5).

Table 6.5: Interactive effect of planting dates and fertility levels on vigour indices of SC701 maize hybrid during 2014/15 (1st year) and 2015/16 (2nd year) season

Planting dates (P)	Fertility (F)	TSW		SMC	
		1st year	2 nd year	1st year	2 nd year
Early	Control	542.10b	495.70a	27.08a	62.24a
	Minimal	664.10c	696.20c	24.35a	61.47a
	Optimal	690.90c	659.00c	24.83a	59.38a
Mid	Control	506.60b	592.80b	23.20a	57.12a
	Minimal	671.60c	696.20c	21.85a	55.59a
	Optimal	670.40c	697.80c	24.17a	54.47a
Late	Control	338.50a	462.50a	20.75a	63.05a
	Minimal	394.20a	429.70a	20.92a	59.50a
	Optimal	358.50a	497.20a	21.35a	57.03a
P × F		(P<0.05)	(P<0.05)	(P>0.05)	(P>0.05)
LSD _{P<0.05}		80.05		7.046	4.682
F.test		(P<0.001)		(P<0.05)	
P ¹ LSD _{P<0.05}		31.75		2.583	
F.test		(P<0.001)		(P>0.05)	
F ¹ LSD _{P<0.05}		22.27		2.446	
F.test		(P<0.001)		(P<0.05)	
Season (S ¹)		26.02		1.793	
LSD _{P<0.05})					
F.test		(P<0.001)		(P<0.05)	
P × F ¹		41.09		4.038	
F.test		(P<0.05)		(P<0.05)	
P × S × F ¹		67.25		5.530	

TSW= thousand seed weight, SMC= seed moisture content and 1 = Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons for the three planting dates

Discussion

Understanding the effect of diverse environments on seed quality would allow producer to obtain high seed quality which is essential for high yield and production. Farhadi et al., (2014) explained that environmental conditions during seed formation influences seedling establishment in the subsequent planting season. To obtain high seed quality in maize in the midst of the current climatic variability, ensuring soil nutrients balance and planting under favourable environmental conditions is of great importance. This study showed that interaction of soil fertility level and planting date increase time to reach tasselling and silking during warm

season but decrease during drier season and consequently affect the physiological traits of the progeny seed produced in each season.

The seedling daily germination percentage increased with increasing fertilizer rate, seed lots with optimal fertilization at early and mid-planting dates exhibited higher germination percentage in comparison to seed lots from late planting. This could be attributed to higher photosynthates accumulation and the presence of optimal temperature and rainfall during the crop growth and development stages. In addition, increasing fertilizer dosage during late planting had little or no effect on the daily germination percentage, which could be attributed to decline in the release of soil nutrient. It might have impaired the rate of nutrients uptake causing reductions in net assimilation rate and seed dry weight accumulation. Wambugu, et al. (2012) showed that lower seed weight will have lesser vigour and might not be able to attain maximum germination.

The increase in seedling vigour index, germination velocity index, mean germination time, shoot and root length obtained at optimal fertilized trial under early planting during 2014/15 and mid planting during 2015/16 seasons showed that favourable environmental conditions greatly determined seed vigour. Optimal fertilization coupled with adequate precipitation and temperature experienced during early planting in 2014/15 and in mid planting in 2015/16 season. Thereby, providing nutrients for the formation of the seedling embryonic axis and storage organs and influenced capacity of the seed to attain higher seed mass. Ochieng et al., (2013) reported that fertilizer application facilitated the production of enzymes, which help in metabolic processes of germination and growth. Since, radicle and shoot lengths are indices of seedling development and vigour; they are used as a criterion for assessment of seedling growth and vigour (Hampton and TeKrony 1995). Reduced seedling length potentially decreased germination and seedling emergence rate that leads to poor stand establishment in

the field crops (Ghassemi-Golezani et al., 2011). The observed low performance in seedling vigour index, germination velocity index, mean germination time, seedling length of seed lots obtained during 2015/16 in comparison with 2014/15 season could be attributed to the severe water stress caused by low rainfall and high temperature experienced during the maternal plant seed developmental stages which might have initiated reduction in its seedling mass and seedling length.

Low seedling length, fresh and dry mass, thousand seed weight under low soil fertility and late planting might be due to decline in the soil nutrient coupled with extreme temperature during the final phase of grain filling. Thus, lead to poor seedling germination and vigour. Seed development and maturation during early planting fall between February and March when the mean temperature and precipitation were 23.9 °C and 27.8 °C and 148.6 mm and 102 mm during 2014/15 and 2015/16 seasons respectively. This created a favourable growing environment that led to higher accumulation of photosynthates as expressed through heavy thousand seed weight. The effectiveness of fertilizer application is greatly influenced by the prevailing weather conditions is generally higher during wet year than during dry years (Yamoah et al., 1998). Thousand seed weight was influenced by climatic conditions, particularly high temperature during the final phase of grain filling. In addition, Dornbos Jr. (1995) reported that seeds produced under conditions of low-soil fertility expressed poor germination and vigour due to stress during their maternal plant development and maturation causing reduction in the progeny seed quality. Nitrogen and phosphorus nutrition enhanced various physiological and biochemical processes such as germination, enzymatic activities, carbohydrate metabolism and accumulation of photosynthates (Taiz and Zeiger 2010). Thus, induced increase in seed mass and weight. In addition, the variance between fresh and dry mass

might be due to difference in the water content of the tissues since water is important for germination.

This study showed that early-planted maize passed through lower temperature during early phases and completed their life cycle taking longer period. While, seed developmental stages of lately planted maize fall under lower temperature and erratic rainfall causing lower seed weight. In addition, progeny seeds of the same genotype planted under different environmental conditions had different germination and vigour. Late planting maize experienced unsuitable environmental conditions during their vegetative growth, which could have resulted in synthesis, and translocation of low photosynthates thus resulted in lower seed weight and quality. Gul et al., (2012) reported that smaller endosperm and lower seed weight and size were the main cause of low vigour in seed harvested from late-planting. Oskouie and Divsalar (2011) reported that if mother plants undergo high temperature stress, it induced physiological disorders in seeds causing delay in its progeny seed, seedling growth, emergence and yield. Khan et al., (2014) observed that application of fertilizer improves maize quality. Therefore, seed harvested under optimal fertilized trials and suitable weather condition had high germination performances than those under extreme weather conditions. This study confirmed the observation of Carson and Ozores-Hampton (2014) who explained that the patterns of nutrient release through fertilizer applications were greatly affected by temperature, moisture, and other conditions that alter biological activity. Therefore, application of fertilizer during unfavourable environmental conditions as observed in late planting had little or no positive effect on the quality of seed produced.

The speed of germination is a direct measure of seed vigour, vigorous seed lots have more germination speed compared to non-vigorous seeds (Khan et al., 2003). The high speed of germination of seed lots with optimal and minimal fertilization from early planting in

comparison to those obtained with optimal fertilization from late-planting, showed that progeny seeds that experienced favourable weather conditions with either minimal or optimal fertilization produced seed with higher germination and vigour than the progeny seeds that experienced adverse weather conditions with optimal fertilization during their growth and development.

Conclusion

The environmental conditions in which hybrid seed is produced have resultant effect on its progeny seed quality as observed in this study. Seed lots without application of fertilizer as well as those seed produced under unfavourable environmental conditions (late planting) such as extreme temperature and rainfall had low vigour as measured by electrical conductivity of seed leachate, seed weight, seedling mass, germination percentage and speed of germination. Early and mid-planting improved the progeny seed quality in both warmer and drier seasons respectively. Application of nitrogen and phosphorus fertilizer improved seed quality at each planting date under warmer season but had no positive effect on the quality of seed produced during late planting especially under drier season. Minimal and optimal fertilizer application enhanced the seed quality under favourable environmental conditions. Thus, farmers could still obtain high seed quality with minimal fertilization provided there is favourable weather conditions.

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CHAPTER 7

Effect of soil fertility and harvesting stage on maize seed quality under rain fed conditions¹

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Abstract

The management practices during seed developmental stages are very important for boosting the seed quality and seedling establishment in the next growing season, especially under rain-fed conditions. However, its influence on improving seed harvested earlier before unfavourable weather arrives is less understood. The aim of this study was to determine the effects of soil fertility and crop maturity stage on maize seed quality. Seeds of maize cultivar SC701 were harvested at milk (R_3), dent (R_5) and physiological maturity (R_6) stages from two field trials during 2014/2015 and 2015/16 summer seasons. They were dried to less than 12% moisture content. Field trials were designed as split plot with fertility level (main factor) and harvesting stage (sub plots) arranged in randomized complete blocks replicated four times. Seed quality was evaluated using the standard germination test, vigour indices and electrical conductivity test according to ISTA rules. The results showed highly significant interactions ($P < 0.001$) between fertility level and harvesting stage for daily germination, germination velocity index, vigour index, seedling length, thousand seed weight, seedling mass and electrical conductivity. Physiologically matured seeds with optimal fertilization had the highest seedling germination performances at both sites and seasons. In addition, seeds harvested at dent stage with optimal fertilization gave higher seed quality and performed similarly to those harvested at physiological maturity without fertilizer application. Fertility level had little or no effect on the germination performance of seedlings from milk stage. Maize seed attained optimum seed quality at physiological maturity. However, with optimal fertilization under favourable growing season, high seed quality could be obtained at dent stage of development.

Keywords: Fertilizer, Germination, Maturity, Seedling, Vigour

Introduction

The management practices during seed development are very important for boosting the seed quality and seedling establishment in the next growing season especially under rain-fed conditions. Considerable work has been reported on these aspects but efforts are still required to improve the management techniques to attain high quality seed and production (Ferreira et al. 2013; Wambugu et al. 2012).

The soil fertility status has a great role to play in increasing maize seed production and quality. Researches have shown that if mother plants undergo adequate soil nutrition, its progeny seeds will have more vigour compared to those with poor nutrition. Seed quality depends mostly on genetic makeup of the seed, soil, climate and management factors experienced by the maternal plant during growth and development (Perry 1980; Tekrony and Egli 1997; Marcos Filho 2015). The management practices during maize seed development lead to a significant increase or decrease in seed vigour and viability.

Maize (*Zea mays L.*) is a major staple food crop grown by small holder farmers and constitutes approximately 70% of seed production in South Africa (Von Bormann and Gulati 2014). Some of the smallholder's farmers have now tended to employ the use of hybrids because of its desire high yield trait and quality under extreme conditions, which remains important. However, maize has high soil fertility requirement because it is an efficient nutrients user due to its deep rooting system (Uribe-la-rea et al. 2009).

Nevertheless, most soils in South Africa are deficient in major nutrients such as nitrogen (N) and Phosphorus (P) due to over-exploitation of the natural soil fertility. While majority of the farmers do not apply, or apply below recommended fertilizer rate during plant growth and development, its effect on seed quality is adverse and seriously reduces yield by delaying plant growth and development. This is particularly so as maize plants accumulate N from seedling

emergence to maturity at various rates. Nitrogen plays a key role in seed filling, increased seed protein content and may increase dry matter which is a good index for seed quality (Warraich et al. 2002). In addition, phosphorus nutrition plays an important part in many physiological processes, cell reproduction, biological nitrogen fixation, root development, early silking, seed formation, crop maturity, lower seed moisture content, yield and quality during plant growth (Armstrong 1999). Consequently, the lack of phosphorus is as important as the lack of nitrogen and limit maize performance.

The requirement and utilization of these nutrients in maize depend on environmental factors and maize growth stages. Dornbos Jr. (1995) explained that for better crop development, soil fertility has great importance on plant nutritional status, which might affect seed quality. Valerie (2006) showed that small holder farmers in Sub-Saharan Africa use very low rate of fertilizer averaging about 10 kg/ha of NPK. Nevertheless, it is well known that optimal fertilization can directly increase crop yield and quality by improving soil nutrient availability and sustainability through improving soil physical and chemical resilience to climate variation (Blair et al 2006). However, it is not clear whether optimal fertilization can still improve the quality of seed harvested before attaining physiological maturity due to adverse weather conditions or infestation of pest diseases. The role of improved soil fertility on morphological and physiological changes that occur during maturation process may therefore offer some promises towards improving the seed quality of maize seed harvested before reaching physiological maturity. In agro ecological condition of South Africa, there is little data to show effect of soil N and P status on the maturity stages and its effect on maize seed quality. Understanding the role of fertilization in response to maize maturity stages during seed development will be imperative for boosting the production and quality of maize during the forecast climate changes. Therefore, this study focus on the interactive effect of soil fertility

levels and maturity stages at harvest of SC701 maize hybrid in relation to its seed germination and vigour.

Material and Methods

Field experiments were conducted on chromic luvisols soil type, which was low in organic carbon, available nitrogen and phosphorus at two locations for two consecutively summer 2014/2015 and 2015/2016 seasons. The experiments sites were situated at the university of KwaZulu-Natal's Ukulinga research farm (29°37'S; 30°16'E; 775 m a.s.l.) and Baynesfield site (29°75'S; 30°30'E; 850 m a.s.l.). Ukulinga research farm is classified as semi-arid with annual rainfall ranging from 644 - 838 mm; almost 80% occur around October to April and mean annual temperatures of 18.4°C. Baynesfield is classified as humid climatic zone with an annual rainfall ranging from 800- 1280 mm and mean annual temperatures of 17°C, summer experience heavy mist while light to sever frost and hail occur in winter (Smith 2006). Soil texture at both sites was clay-loam though Baynesfield had higher clay percentage than Ukulinga site (Table 7.1). Conventional tillage system was practices at both sites except during 2015/2016 season where conservative tillage was adopted at Baynesfield site. Foundation seed of SC701 maize hybrid of uniform size were obtained from McDonalds Seed Company, in KwaZulu-Natal, South Africa were planted during 2014/2015 season and its progeny was planted during 2015/2016 season.

Crop management

The trials were planted at the onset of the rainy season in both seasons (23th and 24th November 2014 and 19th and 20th November 2015) for Baynesfield and Ukulinga sites respectively. Prior to planting, soil samplings were collected from top soil (0-20 cm) randomly

and analysed for selected physicochemical properties. Based on soil fertility results (Table 7.1), fertilizer treatment consisted of N and P since the soil was not deficient of K. Control (no fertilizer application, 0: 0 kg/ha), minimal (application of half recommended fertilizer quantity, 100 kg/ha: 10 kg/ha) and Optimal (application of the recommended fertilizer quantity, 200 kg/ha: 20 kg/ha) for urea (N) and triple super phosphate granule fertilizer (50% P) respectively. For N fertilizer, each level was split into two equal parts (half was applied at planting and other half at 8 weeks after planting). Weeding was done by hand hoeing once at Baynesfield according to Akinnuoye-Adelabu et al. (2017), and twice at Ukulinga due to it high weed bank. Pesticide was sprayed to control the infestation of insect pest.

Table 7.1: Physicochemical properties of soil at (0 - 20 cm) before setting up the experiments at Ukulinga and Baynesfield sites in 2014/2015 and 2015/2016 planting seasons

Site	Density (mg/L)	P (mg/L)	K (mg/L)	N (%)	Ca (mg/L)	PH (KCl)	Mg (mg/L)	Mn (mg/L)	Cu (mg/L)	Exch. Acidity (C mol /L)	Total cations (C mol/L)	Clay (%)	*Soil texture	Organic Carbon (%)
Baynesfield (1 st season)													Clayey loam	3.40
	1.60	20	335	0.31	1511	5.45	373	19	4.8	0.14	11.61	43		
(2 nd season)													Clayey loam	3.25
	1.46	18	342	0.32	1582	5.62	371	20	4.6	0.13	12.35	42		
Ukulinga (1 st season)	1.18	38	424	0.23	1739	4.45	581	27	10.8	0.18	14.72	31	Clayey loam	2.30
(2 nd season)	1.13	32	427	0.23	1851	4.80	683	29	8.2	0.11	16.20	31	Clayey loam	2.23

Field Layout and Experimental Design

The experimental design was split design arranged in randomized complete block design where fertility levels (control, minimal and optimal application) were the main plot and sub-plot were the different stages of maturity with four replications. The size of each fertility treatment trial was 150 m² and had sub plot size of 6 m² containing maturity stages. Planting spacing was 0.5 m x 0.75 m, translating to 26,667 plants/ha. Two seeds per station were planted directly at a depth of 25 mm and later thinned to one seedling per station at four weeks after planting (WAP).

Weather data

Daily weather data were obtained from an automatic weather station (AWS) Agricultural Research Council-Institute for Soil, Climate and Water (ARC-ISCW) network of automatic weather stations located within Ukulinga Research Farm and Baynesfield estate. Weather parameters that were considered were rainfall (mm), maximum (T_{\max}) and minimum (T_{\min}) air temperature (°C).

Data collection

Seed Harvest

A standardized maize development stage system was used to identify the harvesting stages (Ritchie et al., 1992). Maize ears were harvested at three stages of development, milk stage (R_3) at 18 days after silking (DAS), dent stage (R_5) at 42 DAS and harvest maturity stage (R_6) at 58 DAS. At each harvest six ears were randomly selected in each plot and first ear from the top of the plant was harvested by hand. Thousand-seed weight (TSW) was determined by counting hundred seed from each treatment then expressed in thousand grams. Harvested ears

were placed on benches in the glasshouse under dry conditions and allowed to dry < 12% moisture content. Dry seed from the middle and basal sections of maize ears were threshed by hand and stored at 4°C in the cold room until further analysis.

Electrical conductivity (EC)

A representative sample of seeds (about 1 kg) from each treatment reduced in the laboratory to obtain the working sample was used. Electrical conductivity was measured using the R&A CM100 Model Single Cell Analyzer. One hundred seeds from each treatment were individually rinsed in distilled water to remove the dirt around the seed coat before weighing then put into cells; each cell was filled with 2 ml of distilled water. The seeds were then arranged into the cell on the tray. Electrical conductivity for each treatment was then measured over a period of 24 hours. It was then computed according to the formula below:

$$EC = (\text{micromhos}) / \text{Weight of seed (g)}$$

Laboratory standard germination test

Germination test were carried out on the seed harvested at each harvesting stages under each fertilizer level according to (ISTA 2010). Hundred seeds were randomly selected from each treatment and each experimental unit consisted of 25 seeds with four replications. The rolled paper towels were put in sealed plastic bags to avoid moisture loss and incubated Labcon growth chambers (Labcon laboratory Equipment Germany L.T.I.E) with temperature set at 25°C for 7 days. Daily count of germination was based on defining germination as radicle protrusion of 2 mm. Observations were made daily for daily germination (DG), final germination percentage (FG) on day 8, according to AOSA (1992) guidelines. Upon termination of the experiment, 10 seedlings from each replicate and treatments were randomly selected for vigour indices which were root length (RL) and shoot length (SL), root: shoot

ratios (R:S), seedling vigour index (VI), fresh mass (FM) and dry mass (DM). Seedling dry mass (DM) was determined by oven-drying seedlings at 70°C for 72 hours and weighing them afterwards.

Seedling vigour was calculated according to the formula by (Abdul- Baki and Anderson 1973):

Seed Vigour Index (VI)

$$= (\textit{shoot} + \textit{root length}) \times \textit{germination percentage}$$

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

$$MGT = \frac{\sum fx}{\sum f}$$

where: MGT = mean germination time,

f = the number of seed completing germination on day x, and

x = number of days counted from the beginning of germination.

Germination velocity index (GVI) which measure speed of seedling germination was calculated according to Maguire (1962) formulae:

$$GVI = \frac{G_1}{N_1} + \frac{G_2}{N_2} + \dots \frac{G_n}{N_n}$$

where: GVI = germination velocity index,

G₁, G₂...G_n = number of germinated seeds in first, second... last count, and

N₁, N₂...N_n = number of sowing days at the first, second... last count.

Description of statistical analysis

A Bartlett's homogeneity of variances was carried out on the fertility levels and harvesting stages at both sites in each season. There were significant differences at 1% level for all the data showing common variance between the sites. Hence data from sites were pooled for subsequent analysis. Data collected were analysed using split plot from GenStat® (Version 16, VSN International, UK) statistical package. Multiple comparison tests were done using Fisher's least significant difference (LSD) at the 5% level of significance

Results

Weather data

Weather data obtained for the two sites were in conformity with long term weather data reported for Ukulinga and Baynesfield. Comparing the two planting (2014/15 and 2015/16) seasons, weather conditions at both sites were a bit similar in 2014/2015 season because plant growth and development occurred nearly at the same time (Fig.7.1). Also, maximum and minimum temperatures were relatively similar though, Baynesfield have higher T_{\max} and T_{\min} (26.9°C, 14.4°C) than Ukulinga (25.4°C and 15.9°C) in 2014/15 season. Maximum and minimum temperatures were consistent with long-term temperature averages of 25.6 and 18 °C. However, weather data for 2015/16 deviated marginally with an average temperature increase of 2.3°C (November to March) from the observed annual mean maximum temperatures for the months. Comparing the two seasons, maximum and minimum temperatures were higher in 2015/16 (28.1 and 15.6°C) than 2014/15 (24.9 and 14.9°C respectively) which were not in conformity with the long-term T_{\max} and T_{\min} . Rainfall received at both sites and seasons up to each harvesting stages differed (Fig 7.1). While, the rainfall distribution in 2015/16 was quite lower compared to those received in 2014/15 season at both sites. Almost 80% of rainfall received during 2015/16 was received from January- March while

the rest were sparingly distributed. Also, there were more days of no rainfall during the reproductive stage of the crops in 2015/16 than 2014/15 season (Fig 7.1). The observed results indicated high accumulation of heat unit and occurrence of water stress which hastened crop development and reduced the grain filling period in 2015/16 than 2014/15 seasons. Though, Baynesfield received higher rainfall than Ukulinga site in each season. The weather data indicated more favourable environmental conditions for the growth and development of maize in 2014/15 compared to 2015/16 season.

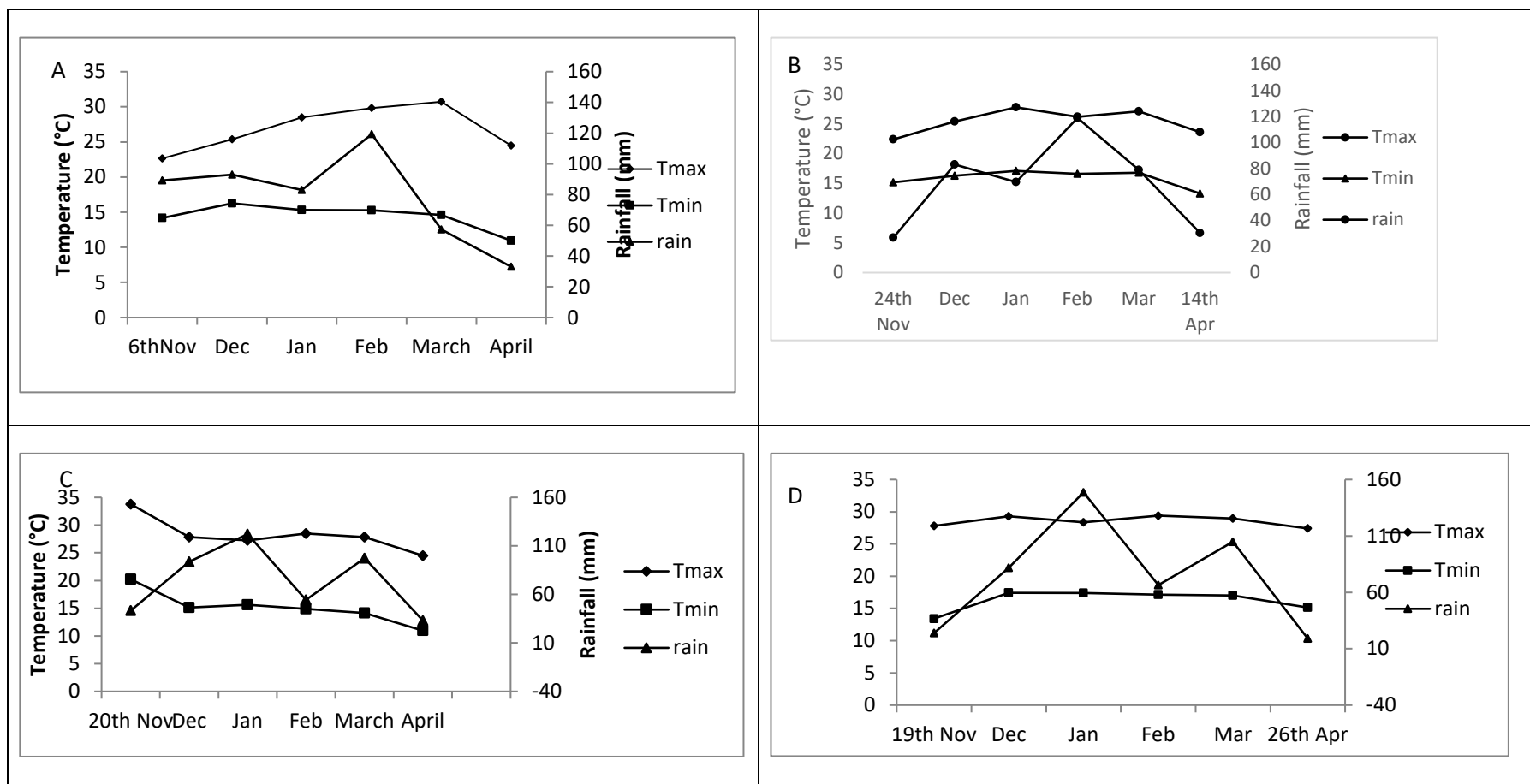


Figure 7.1: A and B = weather data during 2014/15, C and D = weather data for during 2015/16 seasons for Baynesfield and Ukulinga sites respectively.

Standard germination test

The interaction of fertility level \times harvesting stage and fertility level \times harvesting stages \times site significantly influenced ($P < 0.001$) the seedlings daily germination during 2014/15 season. The seedling daily germination from each seed lots at both sites differed. Seedlings from Baynesfield site having higher daily germination compared to seed lots obtained from Ukulinga site. The daily germination improved with delay in harvesting, from milk stage to physiological maturity regardless of the fertility levels experienced. No difference was observed in the daily germination of seed lots obtained under minimal and optimal fertilization. Clear distinction existed in daily germination among the seeds from each of the harvesting stages. It took seeds from dent stage under minimal and optimal fertility levels five days to reach 74% and 77% respectively while physiological mature seeds attained 100% within 4 days (Fig 7.2). This study showed that planting environment had effect on the seed daily germination and varied with season.

The seeds obtained during 2015/16 season showed significant interaction ($P < 0.05$) between fertility level \times harvesting stage and highly significant interaction ($P < 0.001$) among fertility level \times harvesting stages \times site for daily germination. Higher daily germination was observed in seeds from Baynesfield at each fertility level and harvesting stages compared to Ukulinga site (Fig. 7.2). Seeds from milk stage could not attain maximum germination though seeds under optimal fertilization from Baynesfield and Ukulinga sites had their highest germination at 70% and 51% respectively within four days. Seeds harvested at dent stage under minimal and optimal fertility levels attained maximum germination of 97% and 99% respectively within four days. Although, physiologically mature seeds had the highest germination of 100% within five days. No statistical differences were observed between seed lots from dent stage with

optimal fertilization and physiologically mature seeds regardless of their fertility levels (Fig 7.2).

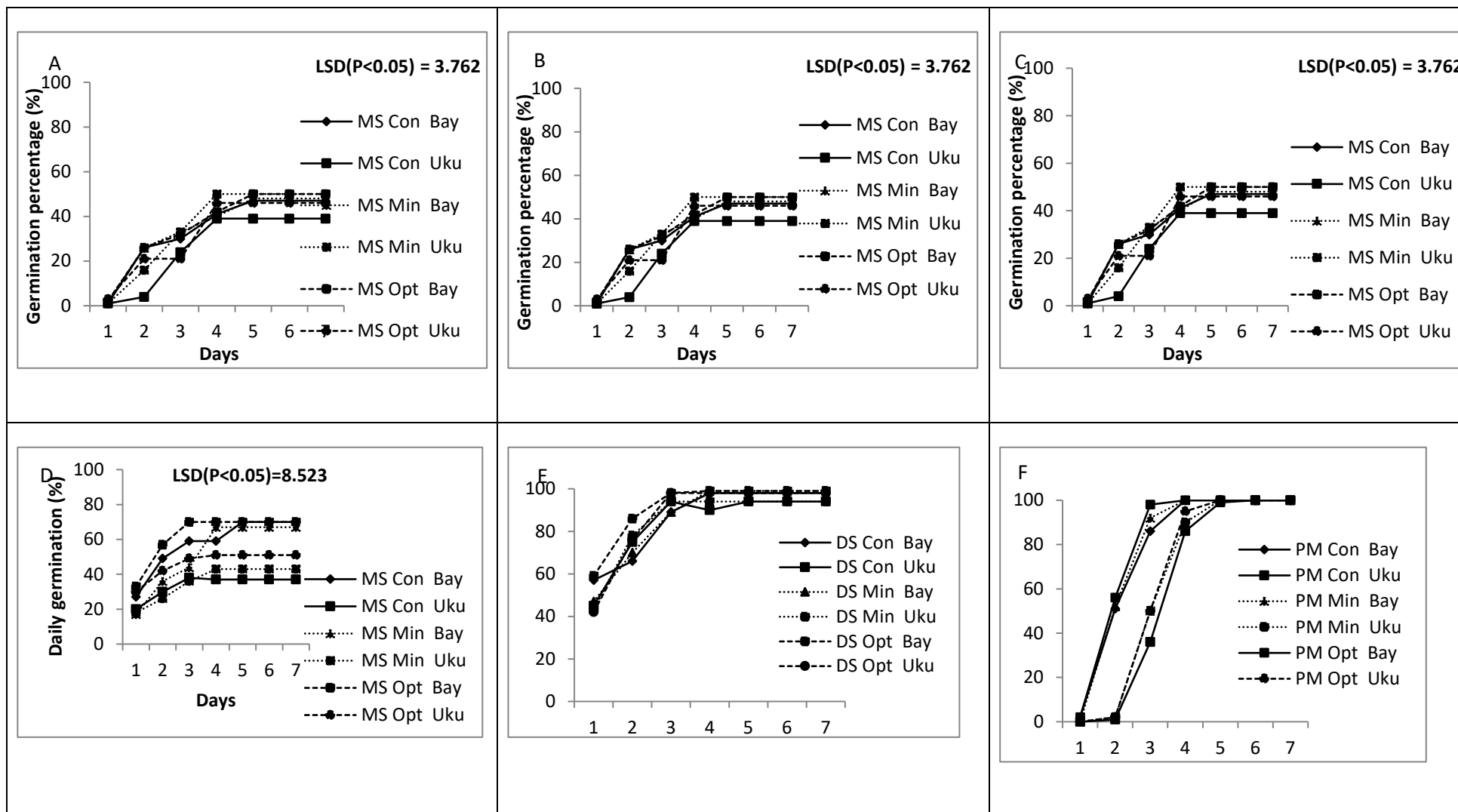


Figure 7.2: A, B and C= Effect of fertility level and harvesting stages on daily germination percentage at Ukulinga and Baynesfield sites during 2014/15 while D, E and F = Effect of fertility level and harvesting stages on daily germination percentage at Ukulinga and Baynesfield sites during 2015/16 seasons. MS = milk stage, DS= dent stage, PM= physiological maturity, Con =control (without fertilizer), Min= minimal fertilizer, Opt = optimal fertilizer, Uku = Ukulinga, Bay = Baynesfield site.

The final germination percentage of seedlings obtained in 2014/15 season showed no significant differences ($P > 0.05$) between the sites and among interaction of fertility level \times harvesting stages, though significant difference ($P < 0.05$) occurred among fertility levels and harvesting stages. An increasing trend in FG of seedling was observed with increase in fertilizer rate and delay in harvesting (Table 7.2). During 2015/16 season, significant interaction ($P < 0.05$) between fertility level \times harvesting stages existed for FG. Also, FG increases with advancement in harvesting. Interestingly, seed lots harvested at dent stage and those that reached physiological maturity gave the highest FG and performed similarly. Over the two seasons, harvesting stages, fertility levels and sites significantly influenced the final germination as well as their interactions (Table 7.2).

Vigour indices

The seedling vigour index was significantly affected ($P < 0.05$) by the interaction of fertility levels \times harvesting stages in both seasons. Seedling vigour indices obtained among seeds harvested at milk stage were the lowest and performed similarly irrespective of fertilizer rate while at dent stage, optimal fertilization improved seedling VI and was at par with the VI obtained in physiological mature seeds without fertilizer application. Overall, interaction of fertility level \times harvesting stage significantly influenced ($P < 0.001$) the seedling vigour index at both sites and seasons. Also, their interactions significantly affected ($P < 0.05$) the VI. The seedling vigour index produced by physiological mature seed at each fertility level in 2014/15 was higher than those obtained in 2014/15 season.

The interaction of fertility level \times harvesting stages had no significant effect ($P > 0.05$) on the seedling MGT during 2014/15 season. Though, seeds from milk and dent stage had higher mean germination time (lower speed of germination) compared to physiologically mature seeds. However, significant interaction existed ($P < 0.05$) between fertility level \times harvesting

stages for MGT in 2015/16 season. Physiologically mature seeds under optimal fertilization had the highest speed of germination. Seeds from dent stage with optimal fertilization (1.96 days) and seeds from physiological maturity stage without fertilization (1.96 days) performed similarly while seed lots harvest at milk stage with optimal fertilization had the highest MGT (2.24 days). Overall, MGT varied significantly at each harvesting stages across sites and seasons. Significant interaction ($P < 0.001$) was only observed for MGT at fertility level \times harvesting stages \times season. The germination velocity index was significantly influenced ($P < 0.05$) by the interaction of fertility level \times harvesting stage in both seasons. Seedling from 2014/15 season had higher GVI compared to those obtained in 2015/16 season (Table 7.2). The GVI improved with increasing fertilizer rate and advancement in harvesting stages at both seasons. Physiologically mature seeds with optimal fertilization had the highest GVI (25.03 and 14.58) in 2014/15 and 2015/16 seasons respectively. While the lowest GVI was found in seeds harvested at milk stage (6.32 and 9.59) respectively. Overall, harvesting stages \times fertility levels significantly affected ($P < 0.001$) the seedling GVI at both sites across the seasons and likewise their interactions.

The seedling electrical conductivity was significantly affected ($P < 0.05$) by the interaction of fertility level \times harvesting stage across seasons. Seed harvested at milk stage produced the highest leachate in both seasons. During 2014/15 season, there were no statistical differences in the EC of seedling harvest at milk stage with minimal and optimal fertilization. Also, fertility levels had no statistical differences on leachate produced by the seedling from dent stage and those that attained physiological maturity (Table 7.2). During 2015/16 season, there was a distinct in seedling EC produced at each harvesting stages and fertility levels and the lowest leachate was observed among the physiologically mature seeds. Overall, fertility level and harvesting stage significantly influenced ($P < 0.001$) the seedling EC at both site and seasons. Also, their interactions significantly affected ($P < 0.05$) the EC. The leachate produced among

the seeds at each harvesting stages and fertility level in 2015/16 was higher than those produced in 2014/15 season.

The seedling root and shoot length were significantly affected ($P < 0.05$) by the interaction of fertility level \times harvesting stage during 2014/15 seasons. Fertility levels had no effect on the seedling RL obtained from milk stage while RL increases with fertilizer rate at dent and physiological maturity stages. In addition, there were no distinct trend in the SL of seeds under different fertility levels from milk stage. However, the SL from seed lots harvested at dent stage under optimal fertilization and those that attained physiological maturity under minimal and optimal fertilization were at par (Table 7.3). During 2015/16, seedling root length was significantly affected ($P < 0.05$) by the interaction of fertility level \times harvesting stages but shoot length was not significantly affected ($P > 0.05$) by this interaction. The seedling root length from dent stage and physiological maturity increased with fertility level and advancement in harvesting. Seedling root length from seed lots at dent stage with optimal fertilization produced higher RL than those obtained at physiological maturity with no fertilizer application.

Overall, harvesting stages significantly influenced ($P < 0.001$) the seedling root and shoot length across the seasons. In addition, seedlings lengths were significantly affected ($P < 0.05$) by fertility level and fertility level \times harvesting stages interaction. The interaction of fertility level \times harvesting stages \times site significantly influenced ($P < 0.05$) the RL while interaction of fertility level \times harvesting stage \times season significantly influenced ($P < 0.05$) the SL (Table 7.3).

The seedling fresh and dry masses were significantly affected ($P < 0.05$) by the interaction of fertility level \times harvesting stage during 2014/15 season (Table 7.3). The highest FM and DM were among physiologically mature seeds with optimal fertilizer while the lowest occurred

seeds from milk stage without fertilizer application. Increasing rate of fertilizer application on the maternal plant has no effect on seedling fresh mass harvested at dent stage. Seedlings from physiological maturity stage under minimal and optimal fertilization performed similarly. Seedling dry mass increased with advancement in harvesting stages and increase in fertilizer application. During 2015/16 season, the fresh and dry mass were significantly affected ($P < 0.001$) by the interaction of fertility level \times harvesting stage. In addition, the highest FM and DM were observed among physiologically mature seeds with optimal fertilizer rate while the lowest occurred among seed lots harvested at milk stage. Overall, the interaction of fertility level \times harvesting stage significantly influenced ($P < 0.001$) the seedling fresh and dry mass at both sites. The interaction of fertility level \times harvesting stage \times site had significant effect ($P < 0.05$) on FM while interaction of fertility level \times harvesting stage \times season significantly influenced ($P < 0.05$) the dry mass (Table 7.3).

Table 7.3: Interactive effect of planting date and fertility level on germination characteristics of SC701 maize hybrid during 2014/15 (1st year) and 2015/16 (2nd year) season

Harvesting stages(H)	Fertility levels	RL (cm)		SL(cm)		R:S		FM(g)		DM(g)	
		1st year	2 nd year	1st year	2 nd year	1st year	2 nd year	1st year	2 nd year	1st year	2 nd year
Milk stage	Control	11.06a	10.75a	7.19abc	6.38a	1.21a	1.23a	4.54a	3.06a	0.15a	0.55ab
	Minimal	10.75a	11.74a	6.44a	6.88a	1.31a	1.58b	4.88a	3.66a	0.18a	0.49a
	Optimal	11.19a	12.19ab	7.00ab	7.25a	1.51a	1.68bc	6.29b	3.82a	0.13a	0.64b
Dent stage	Control	14.25b	13.74bc	8.06bcd	8.18a	1.73a	1.62bc	13.93c	6.89b	0.24b	0.82c
	Minimal	16.31bc	13.85bc	8.63d	8.29a	1.76a	1.91cd	13.91c	7.21bc	0.24b	1.01d
	Optimal	17.88cd	15.90d	10.63e	8.59a	2.00a	1.99de	15.01c	7.71c	0.31c	1.38e
Physiological maturity	Control	15.62bc	15.34cd	8.44cd	7.59a	2.00a	2.04de	21.39d	8.72d	0.35cd	1.50ef
	Minimal	19.00de	18.43e	10.69e	8.20a	1.93a	2.11de	23.95e	9.99e	0.39d	1.60f
	Optimal	21.12e	20.91f	10.56e	9.20a	2.27a	2.23e	24.80e	12.22f	0.48e	2.07g
H × F		(P<0.05)	(P<0.05)	(P<0.05)	(P>0.05)	(P>0.05)	(P<0.05)	(P<0.05)	(P<0.001)	(P<0.05)	(P<0.001)
(LSD _{P<0.05})		2.261	2.098	1.329	0.906	0.300	0.271	1.388	0.798	0.055	0.148
H ¹		P<0.001		P<0.001		P<0.001		P<0.001		P<0.001	
(LSD _{P<0.05})		0.787		0.402		0.128		0.480		0.163	
F ¹		P<0.05		P<0.05		P<0.05		P<0.05		P<0.05	
(LSD _{P<0.05})		1.203		0.595		0.100		0.800		0.196	
Site (s)		P<0.001		P<0.001		P<0.001		P<0.001		P<0.001	
(LSD _{P<0.05})		0.729		0.385		0.091		0.354		0.135	
Season (S ¹)		P>0.05		P<0.001		P>0.05		P<0.001		P<0.001	
(LSD _{P<0.05})		0.729		0.385		0.091		0.354		0.135	
H × F ¹		P<0.001		P<0.05		P>0.05		P<0.001		P<0.001	
(LSD _{P<0.05})		1.511		0.776		0.198		0.965		0.281	
H × s × F ¹		P<0.05		P>0.05		P<0.05		P<0.05		P<0.001	
(LSD _{P<0.05})		2.118		1.105		0.271		1.197		0.394	
H×S× F ¹		P>0.05		P<0.05		P>0.05		P>0.05		P<0.05	
(LSD _{P<0.05})		2.118		1.105		0.271		1.197		0.394	

RL = seedling root length, SL = seedling shoot length, R:S = root: shoot ratio, FM = seedling fresh mass, DM = seedling dry mass, 1 = Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons

The interaction of fertility level \times harvesting stage significantly different ($P < 0.05$) with regards to thousand seed weight at both seasons. Thousand seed weight increased with advancement in harvesting and increasing fertility levels. Overall, the interaction of fertility level \times harvesting stage significantly influenced ($P < 0.001$) TSW (Table 7.4). Also, the interaction of fertility level \times harvesting stage \times season significantly affected ($P < 0.05$) TSW. Delay in harvesting coupled with optimal fertilization increase the weight of seeds obtained at dent stage and physiologically mature seeds but fertility level has little effect on TSW obtained at milk stage.

There was no significant difference ($P > 0.05$) between the interactions of fertility level \times harvesting stage with regards to seed moisture content in both seasons. Overall, harvesting stages had highly significant difference ($P < 0.001$) on the seed moisture content (Table 7.4). The stages of maturity of maize at harvest had great effect on the seed moisture content than the level of fertility experience. Earlier harvested seed gave the highest while the lowest was recorded in seed lot with delay harvesting.

Table 7.4: Interactive effect of planting date and fertility level on seed quality characteristics of SC701 maize hybrid during 2014/15 (1st year) and 2015/16 (2nd year)

Harvesting stages(H)	Fertility (F)	TSW (g)		SMC (%)	
		1st year	2 nd year	1st year	2 nd year
Milk stage	Control	248a	162.60a	80.18a	76.34a
	Minimal	322b	191.40b	78.34a	81.55a
	Optimal	321b	209.40b	78.13a	80.11a
Dent stage	Control	490c	413.20c	58.50a	60.89a
	Minimal	588d	468.70d	58.64a	58.99a
	Optimal	596d	497.60d	55.38a	59.36a
Physiological maturity	Control	585d	421.20c	33.73a	24.05a
	Minimal	678e	489.50d	26.91a	24.96a
	Optimal	842f	562.80e	25.38a	25.13a
H × F		(P<0.05)	(P<0.05)	(P>0.05)	(P>0.05)
(LSD _{P<0.05})		70.200	28.780	4.344	4.045
H ¹		P<0.001		P<0.001	
(LSD _{P<0.05})		25.860		1.900	
F ¹		P<0.001		P>0.05	
(LSD _{P<0.05})		25.240		1.991	
Site (s)		P>0.05		P>0.05	
(LSD _{P<0.05})		27.500		1.384	
Season (S ¹)		P<0.001		P>0.05	
(LSD _{P<0.05})		27.500		1.384	
H × F ¹		P<0.001		P>0.05	
(LSD _{P<0.05})		41.760		3.130	
H × s × F ¹		P>0.05		P>0.05	
(LSD _{P<0.05})		70.680		4.218	
H×S× F ¹		P<0.05		P>0.05	
(LSD _{P<0.05})		70.680		4.218	

TSW= thousand seed weight, SMC =seed moisture content, 1= Statistics refer to the comparison between the 2014/15 and 2015/16 planting seasons

Discussion

This investigation showed that the stage of maturity at harvest and fertility level significantly determined the germination characteristics and vigour of maize seed. Delay in harvesting give more space to accumulation of assimilate and reduced the seed moisture content. Thus, seedling from physiological maturity stage had the highest germination percentage. It was noteworthy that seedling under optimal fertilization from dent stage performed similarly in daily

germination with physiologically mature seeds. This could be attributed to application of optimal fertilizer to the mother plant, which enable it to accumulate photosynthates faster and supply high energy for the enzymatic processes involved during the germination. In addition, maize seed acquire the ability to germinate as early as 35 days after pollination as observed among seedlings from milk stage but were unable to attain maximum germination (Oishi and Bewley 1990; Wang et al. 2016). The differences in final germination percent of seedling at each harvesting stage and fertility levels could be due to variation in photosynthates accumulated in their endosperm. In addition, fertilization enhance the rate of the accumulation leading to differences in seed weight. The ability of seed lots harvested at milk stage to show significant increase in germination could be attributed to the process that initiate germination probably involve several enzymatic processes such as catabolism, anabolism and cell division which do not involve transfer of nutrients. Thus, allowing immature seed to also reach certain germination state. According to Wang et al. (2016) seed viability or germination is usually acquired earlier during seed development. Seeds produced under conditions of low-soil fertility expressed poor germination as observed among the progeny seeds whose parents received no fertilizer application. Poor soil fertility experienced by maternal plants during seed development might have induced some physiological processes in the progeny seeds. This study agreed with Dornbos Jr. (1995) who indicated that insufficient soil nutrient during maternal seed development reduced seed quality of the progeny.

The results of the seedling vigour index, mean germination time, germination velocity index of seed lots harvested at dent stage under optimal fertilization showed that adequate soil fertility enhances the food reserve in the seed endosperm and made its performance at equal with those seeds harvested at physiological maturity without fertilizer application. The increase in the speed of germination of seeds harvested during (warmer) 2014/15 season compared with seed from 2015/16 (drier) season might be due to the increase in the atmospheric temperature, which

lead to temperature stress most especially at the grain filling stage during 2015/16 season. This study agreed with Hatfield and Prueger (2015) who indicated that higher temperature near anthesis have a large negative effect on maize seed quality. The synergistic effect of optimal fertilizer application and delay in harvesting greatly improved the seedling vigour index, germination velocity index in physiologically mature seeds. This could be explained by the fact that physiologically mature seeds contain more food reserves and had the capacity to nourish the embryo longer during germination than seeds harvested at milk and dent stages. Thereby having higher speed of germination. Warraich et al. (2002) reported that fertilizer application in wheat resulted in seeds with higher speed of germination though emphasis was not on stages of harvesting. This study showed that optimal application of N and P improved the seeds harvested at dent stage and made it be at par in seedling vigour index and second best in speed of germination with physiologically mature seeds. Increased seedling vigour index might be due to improve in seed maturation through the fertilizer application resulting higher germination percentage and seedling length.

The decrease in electrical conductance of the seedling produced with delay in harvesting irrespective of fertility levels might be because physiological mature seed had developed thicker cell membrane and has lesser seed moisture, which reduced the amount of leachate produced as compared to seedlings from milk and dent stages. Since electrical conductivity test is an index of seed substances leakage. Increase in seedling leachate produced among the seedlings at each harvesting stages and fertility levels in 2015/16 than 2014/15 seasons might be due to the increase in atmospheric temperature and low rainfall experienced in 2015/16 season which might have affected plant nutrient uptake and hasten the seed developmental stages. This finding agreed with Bitá and Gerats (2013) who reported that high temperature during reproductive development hastened the decline in photosynthesis and decreased seed weight, seed mass and shoot length. The similarity in seedling length obtained in seeds from

dent stage and physiological maturity under optimal fertilizer application implied that improved soil fertility could hasten the accumulation of assimilate in seed that had not attained physiological maturity and increases its vigour since, seedling length is one of the criterion for determining vigour. This study indicated that harvesting earlier led to lower seedling mass (fresh and dry mass), thousand seed weight and higher seed moisture content. The increase in seedling mass and thousand seed weight of seed lots obtained at dent and physiological maturity stages showed that advancement in harvesting coupled with optimal fertilization allowed accumulation of more assimilates to the developing kernels. However, fertility level has little effect on those seed obtained at milk stage, which might be due to the presence of its high percentage of seed moisture content. Decrease in moisture content with advancement in harvesting showed that more accumulation of assimilates occurred with delay in harvesting. Application of optimal fertilizer could only have influenced the rate of this accumulation to certain stage, which was more effective for seed obtained at dent, and physiological maturity stages. This finding concurred with Owolade et al. (2005) who explained that high moisture content reduced seed germination and vigour of maize even after drying to the recommended moisture content. Therefore, harvesting at milk stage (18 DAS) is not advisable irrespective of the soil fertility level or the planting season. This study showed that planting location and season had strong impact on the germination characteristic and vigour of the seed harvested at dent stage and physiological maturity stage than at milk stage.

Conclusion

Improvement in management practices through improving soil fertility and delay in harvesting enhanced the quality seed production during at each season. Seeds harvested at dent stage with optimal fertilization, which were closer to attainment of physiological maturity, exhibited higher germination percentage and vigour indices compared to other seeds at the same stage

but with minimal or no fertilizer application. It was also performed similarly at par with seed harvested at physiological maturity without application of fertilizer. This study suggested that the immature seeds of maize harvested at milk stage have reduced germination and vigour potentials irrespective of the fertilizer rate applied which might be due to high number of immature seeds with relatively low degree of embryo development and high moisture content. Therefore, optimal fertilizer application and harvesting at physiological maturity lead to maximum acquisition of seed germination and vigour, but in the case of adverse weather condition or infestation of diseases and pest seeds harvested at dent stage (42 DAS) under optimally fertilized conditions would still give higher quality seeds than expose the plants to the harsh conditions which would eventually lead to total seed loss.

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CHAPTER 8

Assessment of Nutritional Composition of Maize Hybrid Kernel Based on Soil Fertility and Maturity Stages at Harvest¹

¹In preparation for submission to Agricultural and food science

Abstract

While maize (*Zea mays* L.) hybrids productivity increase with adjustment in management practices, there has been concerns that increase in seed yield might not have resulted in increase in kernel nutrient compositions. This study was conducted to determine the effect of soil fertility status and harvesting stages on the hybrid starch, sugar and protein content of maize kernels. Seeds of maize cultivar SC701 were harvested at milk [18 days after silking (DAS)], dent (42 DAS) and physiological maturity (58 DAS) stages under different soil fertility levels from two field trials and seasons. Split plot design was used where fertility level (main factor) and harvesting stage (sub plots) with four replications was used. The kernels were determined for seed weight, moisture content, sugar, starch, total protein and proline content as a measure of crop response to maturity stages and soil fertility level. The results showed that interaction of soil fertility level \times maturity stage at harvest significantly affected ($P < 0.05$) the sugar, starch and protein content of the maize kernels. Kernel obtained from Baynesfield had higher nutritional contents compared to those from Ukulinga site. During warmer (2014/15) season, increasing fertilizer rate improved the sucrose, fructose and glucose content but during warmer (2015/16) season, increasing fertilizer rate reduced the sucrose content in kernel harvested at dent stage and physiological maturity. While, improving soil fertility had no positive effect on fructose and glucose content at each maturity. The starch and protein contents increased with delay in harvesting and optimal application of fertilizer to the maternal plants. However, none adherence to the recommended fertilizer rate and early harvest before the attainment of physiological maturity resulted in lower photo-assimilate in kernel harvested. Though, kernel harvested at 42 DAS performed second best with regards to all nutrients content studied.

Keywords: Fertilizer, food reserve, kernel, maturity, nutrient

Introduction

Maize (*Zea mays* L) is versatile crop providing food and feed for human beings and livestock as well as main resource for many industrial and commercial products. It has high nutritional value as it contains about 72% starch, 10% proteins, 4.8% oil, 8.5% fibre, 3.0% sugar and 1.7% ash (*Balconi et al.*, 2007). Maize is an excellent source of carbohydrate, which has complete nutrients than any other cereal. The protein content of maize is higher than that of polished rice and its fat content is higher than that obtained from wheat, sorghum and rice (*Yusuf et al.*, 2014).

One of the commonly grown maize hybrids by southern Africa farmer is SC701 cultivar, which is a late maturing cultivar, and its desired trait includes large kernels size and composition. However, it is highly exhaustive crop because of its high nutrient requirement. The composition of nutrient in the kernel may be improved by careful management practices, since kernel assimilation is reported to be dependent upon a supply of soil nutrients which is controlled both environmentally and genetically (*Seebauer et al.*, 2010). *Yin et al.*, (2014) reported that returns in maize production fall with improper management practices as well as with increasing energy, material and human labour costs in the context of global climate change. The environmental conditions of the crop during its seed developmental stages has large effect on the protein quality, starch and sugar biosynthesis and so decision on which management practice to embark on is of great importance (*Bita and Gerats* 2013).

Numerous physiological and biochemical changes occur during growth and development in response to the soil nutrient status of the maternal plant. Nitrates absorbed from the soil by plant roots are normally incorporated into plant tissue as amino acids, proteins and other nitrogenous compounds. While the presence of phosphate in soil facilitates the mobilization of nutrients from the mother plant to the seeds, reduced grain moisture content, increased sugar

and protein content (*Grant and Bittman 2005*). Though, nitrogen fertilization reduces phytic acids content of maize and increases crude protein content significantly (*Gupta et al., 2015*). The protein quality is an important factor for producers and consumers, since it determines the grain quality. Variation in the N supply affects all phases of maize growth and development, activity and composition of ovules (*Uhart et al., 1995*).

The most abundant storage proteins in the embryo are formed during maturation. In the endosperm, zeins are the major storage reserves and their accumulation progressed with stages of maturity. Crude protein declines and starch increases with increasing maturity. However, the role of N and P fertilization on maternal plant growth and seed maturation in response to increasing nutrient compositions is not well documented. Since the nutrient composition was reported to be affected by planting site, fertilization and maturity stage at harvesting stages (*Idikut et al., 2009*).

Little researches on the chemical compositions of SC701 maize hybrid in relation to its soil fertility status and stages of maturity at harvest had been carried out. Nitrogen fertilizer improves maize quality especially its protein contents through increasing crude protein and reducing ash fibre (*Khan et al., 2014*). However, during adverse weather conditions or infestation of pest and disease, farmers may tend to harvest maize kernels earlier.

Understanding the role of improving fertility status through fertilizer application on the nutrient composition of earlier harvested kernel may give some promises towards obtaining maximum nutrient composition in earlier harvested kernels. Presently, not all farmers use the recommended dosage of fertilizers due to cost and its availability. Researches have shown that increase in N fertilizer increases zein contents lowers the amounts of most limiting essential amino acids (lysine and Tryptophan) (*Blumenthal et al., 2008*). Thus, compensated for by increase in size of the germ through increase nutrient uptake caused by fertilizer application.

Therefore, this study focussed on assessing the nutritional compositions of SC701 hybrid maize harvested at different maturity stages and soil fertility levels under rain fed conditions.

Material and Methods

Plant materials and growth conditions

Fertilizer treatments were applied to maize planted in during 2014/15 and 2015/16 summer seasons at two different locations in KwaZulu-Natal (Ukulinga and Baynesfield sites). Prior to planting in 2014/15 and 2015/16 seasons, soil sampling was collected from top soil (0-20 cm) randomly and analysed for selected physicochemical properties (Table 8.1).

Table 8.1: Physicochemical properties of soil at (0 - 20 cm) before setting up the experiments at Ukulinga and Baynesfield sites in 2014/2015 and 2015/2016 planting seasons

Site	Density (mg/L)	P (mg/L)	K (mg/L)	N (%)	Ca (mg/L)	PH (KCl)	Mg (mg/L)	Mn (mg/L)	Cu (mg/)	Exch. Acidity (C mol /L)	Total cations (C mol/L)	Clay (%)	*Soil texture	Organic Carbon (%)
Baynesfield (1 st season)	1.60	20	335	0.31	1511	5.45	373	19	4.8	0.14	11.61	43	Clayey loam	3.40
(2 nd season)	1.46	18	342	0.32	1582	5.62	371	20	4.6	0.13	12.35	42	Clayey loam	3.25
Ukulinga (1 st season)	1.18	38	424	0.23	1739	4.45	581	27	10.8	0.18	14.72	31	Clayey loam	2.30
(2 nd season)	1.13	32	427	0.23	1851	4.80	683	29	8.2	0.11	16.20	31	Clayey loam	2.23

Based on soil fertility results, fertility treatment consists of nitrogen (N) and phosphorus (P) since the soil was not deficient of potassium (K), control (0 kg/ha, 0 kg/ha), minimal (100 kg/ha, 10 kg/ha) and Optimal (200 kg/ha, 20 kg/ha) respectively for urea (N) and triple super phosphate granule fertilizer (50% P). For N fertilizer, each level was split into two equal parts (half was applied at planting and other half at 8 weeks after planting). It was then harvested at three stages of development, milk stage (R₃) which is 18 days after silking (DAS), dent stage (R₅) which is 42 DAS and physiological maturity (R₆) which is 58 DAS according to (Ritchie *et al.*, 1992). At each harvest six ears were randomly selected in each plot and first ear from the top of the plant was harvested by hand. The cobs were shelled and freeze dried and stored at -80°C for physiological analysis. Part of the shelled maize was used for the seed moisture content (SMC) and thousand-seed weight (TSW). Seed moisture content was determined by wet weight basis and was calculated by the following formula:

$$SMC = \frac{M_1 - M_2}{M_1} \times 100$$

Where, M₁ is the mass in grams of the seeds before drying and M₂ is the mass in grams of dried seeds. Thousand-seed weight (TSW) was determined by counting and weighing hundred maize kernels from each treatment and expressing the result as g/1000.

Proline determination

Proline accumulation was evaluated using the kernels according to the method of Bates *et al.* (1973). Freeze-dried seed from each treatment was ground into a fine powder under liquid nitrogen using mortar and pestle. Subsequently, 0.5 g of ground leaf material was homogenized in 10 ml of 3% aqueous sulphosalicylic acid. The homogenate was then filtered through Whatman® No. 2 filter paper. 2 ml of the filtrate was added to a test tube to which 2 ml of glacial acetic acid and acid ninhydrin were added, respectively. The solution was then heated

in a boiling (100°C) water bath for 1 hour. The reaction was then terminated in an ice water bath. The reaction mixture was extracted with 4 ml toluene and vortexed for 15 – 20 sec. The chromosphere containing toluene was aspirated from the aqueous phase, warmed to room temperature and absorbance read at 520 nm using toluene as a blank. Proline concentration was calculated using the standard curve on a dry mass basis (µmol/g). The following equation was used to calculate proline:

$$[(\mu\text{g proline/ml} \times \text{ml toluene}) / (115 \mu\text{g}/\mu\text{mole})] / [(\text{g sample})/5] = \mu\text{moles proline/g of dry weight material}].$$

Determination of soluble sugar concentration

Freeze–dried kernels were ground into a fine powder under liquid nitrogen using mortar and pestle. 0.2 g samples were mixed with 10 mL of 80% (v/v) ethanol and homogenized for 60 s. Thereafter, the mixture was incubated in a water bath (80°C) for 60 min and kept at 4°C overnight. After centrifugation at 12 000 g for 15 min at 4°C, the supernatant was filtered through glass wool and taken to dry in a Savant vacuum concentrator (SpeedVac, Savant, Holbrook, NY, USA). Dried samples were re-suspended in 2 mL ultra-pure water, filtered through 0.45 µm nylon filters. Sugars were analysed according to Liu and Shono (1999), using high performance liquid chromatography (HPLC, LC – 20 AT, Shimadzu Corporation, Kyoto, Japan) equipped with a refractive index detector (RID-10 A, Shimadzu Corporation, Kyoto, Japan) and a Rezex RCM–monosaccharide column (300 mM_7.8 mM) (8 mm pore size; Phenomenex, Torrance, CA, USA). The concentration of individual sugars was determined by comparison with authentic standards.

Total protein content determination

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

Starch determination

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

Data analyses

The mean values of proline, protein, soluble sugar and starch content were taken from the measurements of four replicates. A Bartlett's homogeneity of variances was carried out for all the nutrients under fertility level and harvesting stage at both sites in each season. There were significant differences at 1% level, showing common variance between the sites. Hence data from sites were pooled for subsequent analysis. A split plot design from GenStat® (Version 16, VSN International, UK) statistical package was used. Multiple comparison tests were done using Fisher's least significant difference (LSD) at the 5% level of significance.

Results

Weather data

Weather conditions at both sites were a bit similar in 2014/2015 season. Maximum and minimum temperatures were relatively similar though, Baynesfield have higher T_{\max} and T_{\min} (26.9°C, 14.4°C) than Ukulinga (25.4°C and 15.9°C) in 2014/15 season respectively. Maximum and minimum temperatures were consistent with long-term temperature averages of 25.6 and 18 °C (Fig. 8.1). However, weather data for 2015/16 deviated marginally with an average temperature increase of 2.3°C (November to March) from the observed annual mean maximum temperatures for the months. Comparing the two seasons, maximum and minimum temperatures were higher in 2015/16 (28.1°C and 15.6°C) than 2014/15 (24.9°C and 14.9°C respectively) which were not in conformity with the long-term maximum and minimum temperatures. Rainfall received at both sites and seasons up to each harvesting stages differed (Fig 1). For example, (353.3 mm, 386.6 mm), (373.3 mm, 394.5 mm) and (407.8 mm, 475.0 mm) of rainfall were received up to the milk, dent and physiological maturity stage at Ukulinga

and Baynesfield sites during 2014/15 season respectively. However, the rainfall distribution in 2015/16 was quite lower compared to those received in 2014/15 season at both sites (Fig. 8.1). Almost 80% of rainfall received during 2015/16 was received from January - March while the rest were sparingly distributed. Also, there were more days of no rainfall during the reproductive stage of the crops in 2015/16 than 2014/15 season. Baynesfield received higher rainfall than Ukulinga site in each season. The weather data showed more favourable environmental conditions for maize seed development and maturation in 2014/15 compared to 2015/16 season.

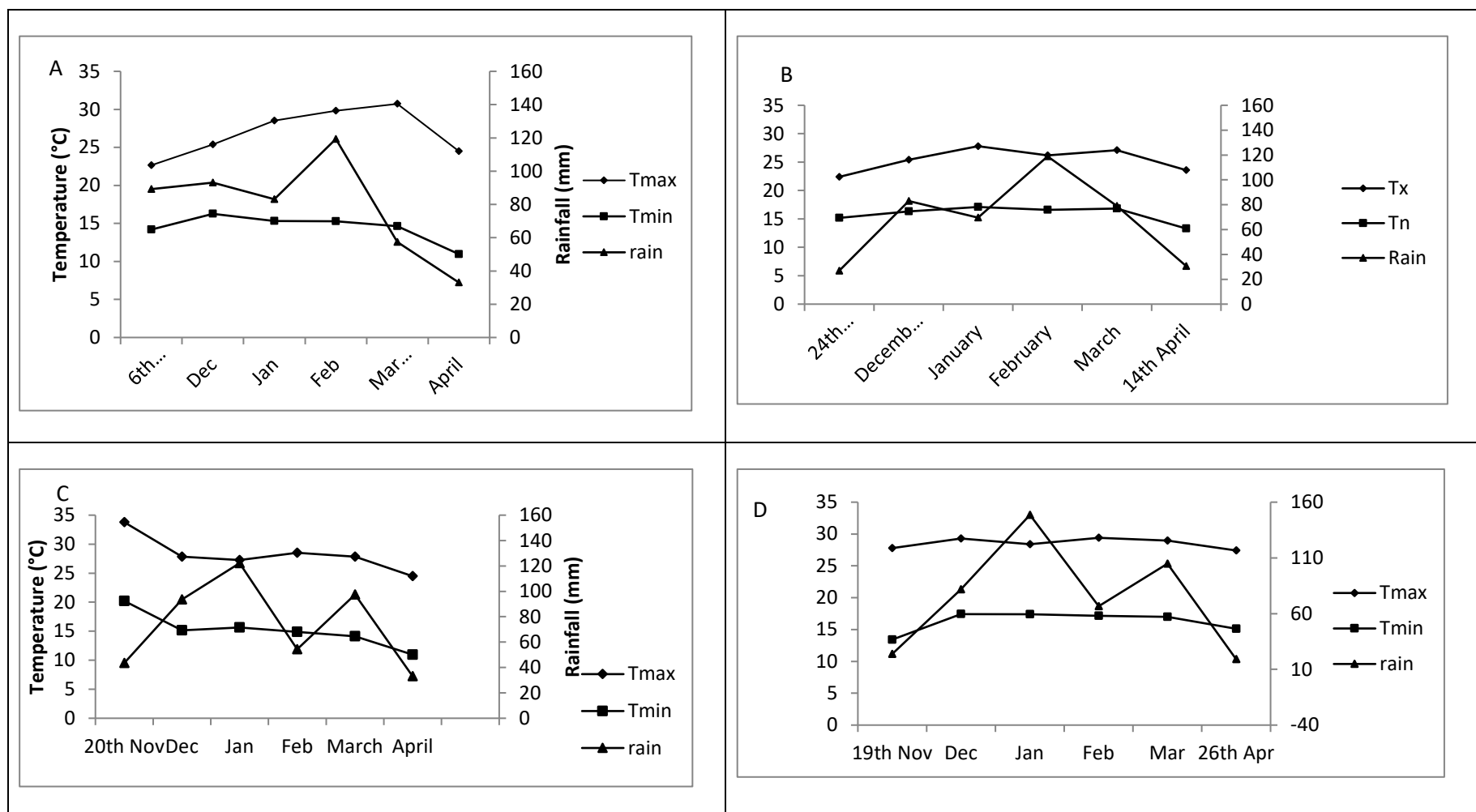


Figure 8.1: A and B = Baynesfield and Ukulinga sites weather data for 2014/15 season, C and D = Baynesfield and Ukulinga sites weather data for 2015/16 season respectively.

T_{\max} = maximum temperature (°C), T_{\min} = minimum temperature (°C), rain = rainfall (mm)

Seed weight and moisture content

The interaction of fertility level \times harvesting stage was significantly different ($P < 0.05$) with regards to thousand seed weight across seasons. Thousand seed weight increased with advancement in harvesting and increasing fertility levels. Overall, the interaction of fertility level \times harvesting stage significantly influenced ($P < 0.001$) TSW (Fig. 8.2). The interaction of fertility level \times harvesting stages \times season significantly affected ($P < 0.05$) TSW. Delay in harvesting coupled with optimal fertilization increased the seed weight obtained at dent stage and physiological maturity but fertility level has little effect on TSW obtained at milk stage.

There was no significant difference ($P > 0.05$) between the interactions of fertility level \times harvesting stage with regards to seed moisture content in both seasons. Overall, harvesting stages had highly significant difference ($P < 0.001$) on the seed moisture content (Fig. 8.2). The stages of maturity of maize at harvest had great effect on the seed moisture content than the level of fertility experienced. Earlier harvested seed had the highest moisture content percentage while the lowest was recorded at physiologically mature seeds.

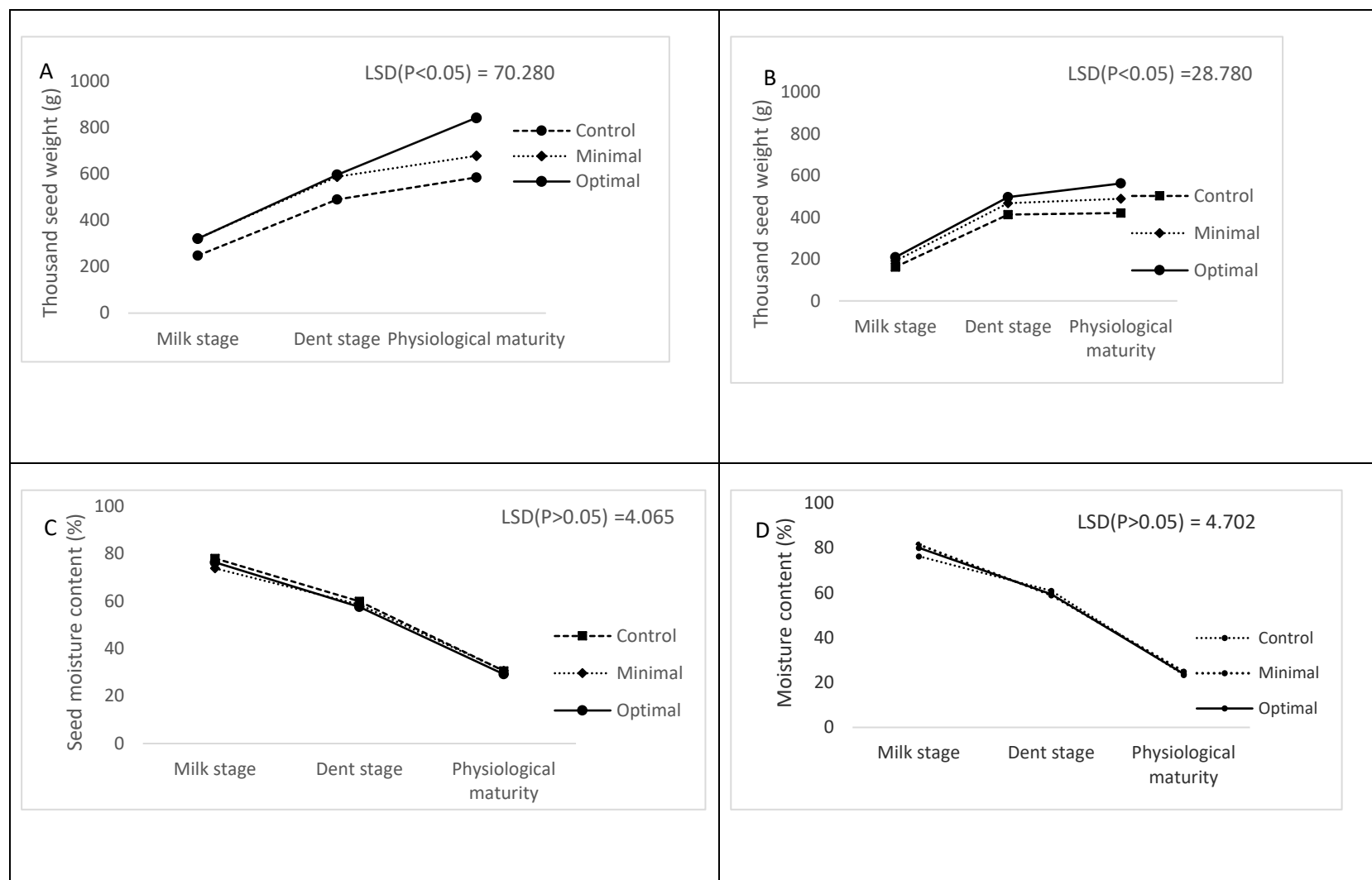


Figure 8.2: A and B= Thousand seed weight from different maturity stages and different fertility levels during 2014/15 and 2015/16 seasons C and D = seed moisture content from different maturity stages and soil fertility levels during 2014/15 and 2015/16 seasons.

Sugar

Significant interaction ($P < 0.001$) existed between fertility level \times harvesting stage for the free sugars (sucrose and glucose except fructose) obtained in the maize kernel during 2014/15 season (Fig. 8.3). Increasing fertilizer rate on the maternal maize plants led to higher sucrose and glucose content in the kernel at each harvesting stages. However, the sucrose content in the kernels increased while glucose content decreased from milk stage (1.12 mg/g, 2.62 mg/g) to physiological maturity (4.17 mg/g, 0.65 mg/g) respectively. Though, no significant interaction existed for fructose, it was observed that application of fertilizer increased fructose sugar at each stage of maturity. During 2015/16 season, the interaction of fertility level \times harvesting stage significantly affected ($P < 0.001$) sucrose, glucose and fructose in the kernel. Increasing the rate of N and P fertilizer application from 0 kg/ha and 0 kg/ha to 200 kg/ha and 20 kg/ha improved the sucrose content in the kernel harvested at milk stage from 2.67 mg/g to 3.49 mg/g but reversed conditions occurred in kernel obtained at dent and physiological maturity stage where increasing rate of fertilizer reduced the amount of the sucrose content (Fig. 8.3). However, application of fertilizer reduced the fructose and glucose content at each maturity stage and no fructose and glucose was detected at physiological maturity in the kernels (Fig 8.3). The sugar content obtained varied with planting location and season. The glucose and sucrose obtained in the kernel from Ukulinga site was higher than those from Baynesfield site while Baynesfield had higher fructose content than those kernels obtained at Ukulinga site. In both seasons, the sugar decreased with increasing maturity from milk to physiological maturity stage. In addition, traces of xlyose and maltose were found in the kernel harvested at physiological maturity.

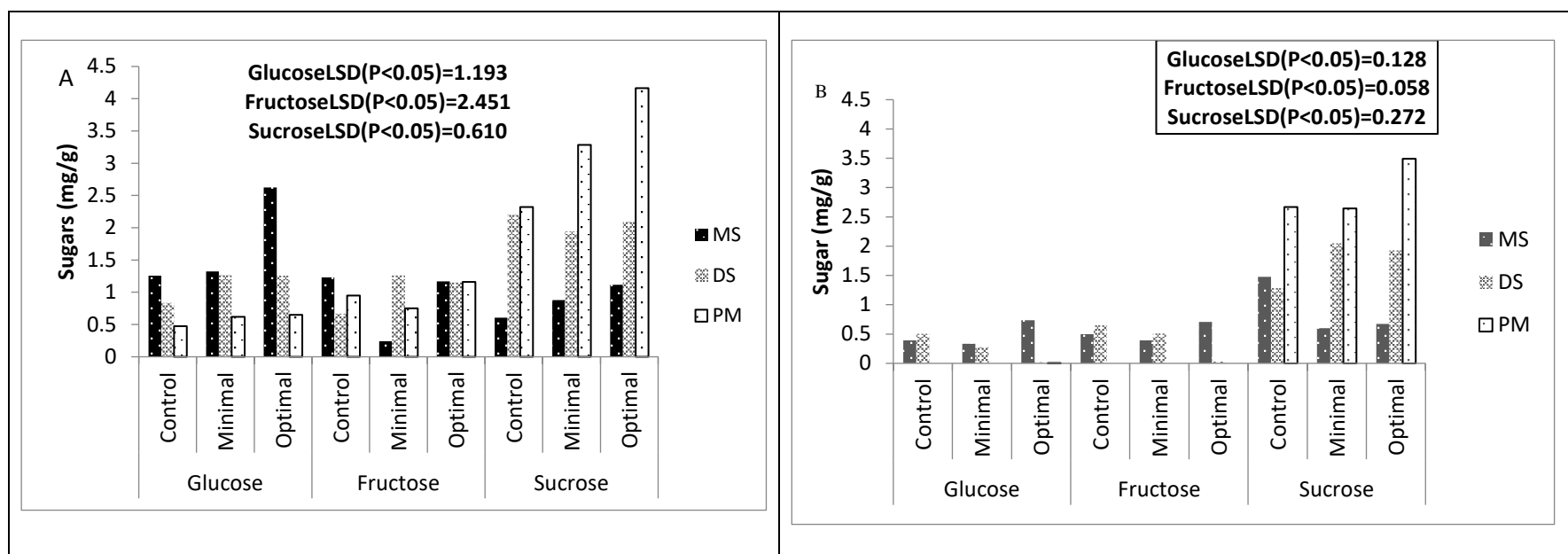


Figure 8.3: A and B =The effect of fertility levels and maturity stages at harvest on free sugar content in maize kernel during 2014/15 and 2015/16 season respectively. MS = milk stage, DS = dent stage and PM = physiological maturity.

Starch

The interaction of fertility level \times harvesting stage significantly affected ($P < 0.001$) the starch content in the kernel during 2014/15 and 2015/16 seasons (Fig. 8.4). At both seasons, increase in fertilizer application improved the starch content of the kernel at each maturity stage. Likewise, the starch content increased with delay in harvesting. The starch content in the kernel differed with planting location, kernels from Ukulinga site was higher 48% higher in starch content than Baynesfield site during 2014/15 season. While kernel harvested at Baynesfield recorded 41% increment in starch content compared with those kernels obtained from Ukulinga site during 2015/16 season.

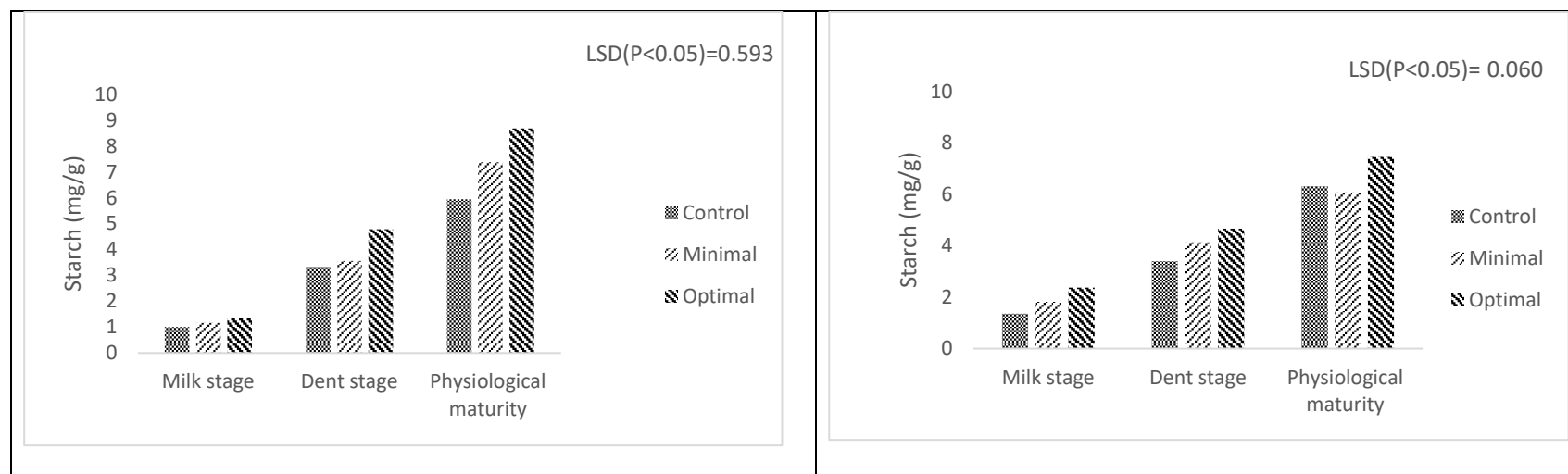


Figure 8.4: A and B=Starch accumulation under different fertility level and maturity stage during 2014/15 season and 2015/16 season respectively. MS= milk stage, DS= dent stage and PM=physiological maturity.

Protein

Significant interaction occurred between fertility level \times harvesting stage ($P < 0.05$) with regards to the soluble protein content in the kernel during 2014/15 and 2015/16 seasons (Fig. 8.5). During 2014/15 season, the lowest protein content was from kernel harvested at milk stage without fertilizer application (0.82 mg/g) while, those harvested under minimal and optimal fertilization at the stage gave similarity in their protein content. No statistical differences were observed in protein content from kernel harvested at dent stage under minimal fertilization (1.46 mg/g) and those that attained physiological maturity without fertilizer application (1.64 mg/g). During 2015/16 season, the lowest protein content was in kernel harvested at milk stage without fertilizer application (1.08 mg/g) and those with minimal application (1.05 mg/g). The protein content obtained in kernel with optimal fertilization at milk stage gave similar value with those obtained in kernels harvested at dent stage. While, the highest protein content was found in kernels harvested at physiological maturity under minimal (2.33 mg/g) and optimal fertilized conditions (2.44 mg/g).

Significant differences existed in the interaction of fertility level \times harvesting stage ($P < 0.05$) with regards to proline content in kernel harvested during 2014/15 and 2015/16 seasons. Application of fertilizer had no statistical effect on the proline content in kernel harvested at milk stage (Fig 8.5). Likewise, proline accumulation in the kernel from dent stage under minimal (10.06 $\mu\text{mols/g}$) and optimal fertilized conditions (9.14 $\mu\text{mols/g}$) were statistically similar. Kernel harvested at physiological maturity without fertilizer application had the highest proline accumulation (21.13 $\mu\text{mols/g}$). During 2015/16 season, similar trends were observed where the lowest proline accumulation were in kernels harvested at milk stage under optimal fertilization (5.93 $\mu\text{mols/g}$) and the highest was in kernel without fertilizer application harvested at physiological maturity (14.38 $\mu\text{mols/g}$). It's was observed that proline

accumulation increased with advancement in maturity and reduced with increase in fertilizer application. Also, it's content varied with location, kernels obtained from Ukulinga site had higher proline accumulation (11.92 $\mu\text{mol/g}$, 10.58 $\mu\text{mol/g}$) compared to those from Baynesfield site (9.17 $\mu\text{mol/g}$, 9.76 $\mu\text{mol/g}$) during 2014/15 and 2015/16 seasons respectively.

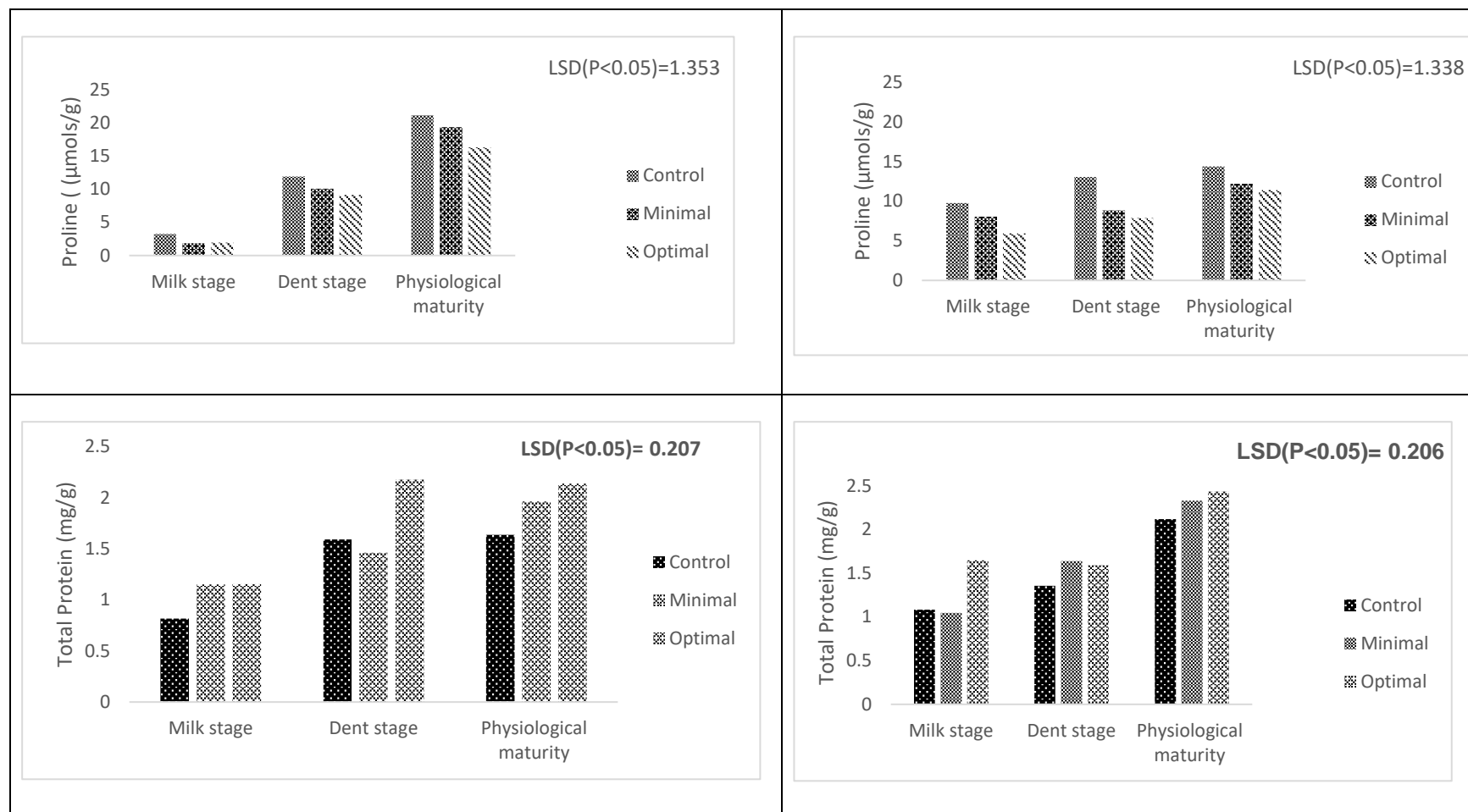


Figure 8.5 A and B: proline accumulation under different fertility level and maturity stage during 2014/15 season and 2015/16 season respectively. C and D : Protein accumulation under different fertility level and maturity stage during 2014/15 season and 2015/16 season respectively. MS= milk stage, DS= dent stage and PM= physiological maturity

Discussion

During maturation, the chemical composition of the kernels undergoes great nutritional changes, especially during the first few weeks after seed fertilization (*Nuss and Tanumihardjo* 2010). The impact of the management practices engaged during maternal plant growth and seed development had great effect on the nutritional composition of the maize kernels. This understanding could be used to obtain higher nutrients in the kernels produced. Since, the chemical composition of maize kernels are influenced by genetic factors, variety, maturity stage at harvest, environmental conditions and geographic location (*Eskandari* 2012).

Improving soil fertility through N and P fertilizer application on maize plants during growth and seed maturation enhanced the food reserve of the kernel, resulted in large thousand seed weight at each harvest stage. Thousand seed weight obtained at each season varied, the observed reduction in seed weight during 2015/16 compared to 2014/15 season might be due to the increment in atmospheric temperature and erratic rainfall experienced. These negatively influenced assimilate production and its translocation to developing seeds. *Marcos Filho* (2015) explained that duration of seed fill is shortened as temperature increases above 30° thereby causing accelerated development in kernels.

The increase in seed weight and decline in seed moisture content in kernel harvested from milk stage to physiological maturity showed that longer duration in seed maturation strongly influence the sink-source relationship in the kernel than improving the plant soil fertility level. Although, optimal fertilizer application increased the seed weight at each harvesting stages. Fertilizer application enhanced the rate of dry mass accumulation most especially at dent stage and physiological maturity but could not compensate for lower seed weight in kernel harvested at 18 DAS (milk stage). Improving soil fertility had no effect on the seed moisture content from each harvesting stage though decrease in moisture content proceeds until hygroscopic equilibrium is

attained at physiological maturity. Decrease in moisture content had been reported to be directly related with delay in harvesting in sweet maize by (Szymanek 2009). However, this study found out that maturity stages at harvest determined the moisture content while the status of the maternal soil fertility have no effect on the kernel moisture content.

The sugar transported into the kernel was affected by soil fertility level and maturity stage at harvest and varied with season. The decline in sugar accumulation in kernel obtained in 2015/16 compared to those in 2014/15 season might be due to increase in atmospheric temperature during the grain-filling period as observed from the weather data. *Lemoine et al.*, (2013) reported similar results in which source-sink relationship was altered by environmental factors. Moreover, sugar accumulated at each maturity stage varied in their concentrations. Fructose and glucose were more dominant while sucrose was in little concentration in kernel harvested at milk stage. The concentration of glucose and fructose decreased while sucrose increases from milk stage to physiological maturity. Similar trend was reported by *Wobus and Weber* (1999) who indicated that during seed development sucrose dominant the kernel followed by maltose, glucose and fructose in trivial amount. While starch is accumulated prominently at physiological maturity. It was observed that improvement in soil fertility greatly increased the rate of glucose and sucrose accumulation in kernel from milk stage (18 DAS) and decrease in as the kernels reached physiological maturity. The conversion of sugar into starch was higher in kernel from milk stage to physiological maturity. *Ghassemi-Golezani et al.*, (2011) observed similar trend where accumulation of reserves in maize seeds followed regressive equations as a function of time and maximum values were obtained at the end of seed filling phase. This study found out that improving the soil fertility level enhanced the rate of sugar accumulation and its conversion to starch even in kernel harvested earlier before attaining maturity. This was contrary to the finding of *Seebauer et al.*, (2010) who explained that maize grown without fertilizer application promoted the greatest concentration of kernel starch which was greater than

kernels grown with the maximum nitrogen supply. However, *Lloyd et al.*, (1997) found that fertilizing the maternal plant increased the nutrients concentration in the barley kernels. Nitrogen and phosphorus fertilization maintains a higher photosynthetic rate thus providing carbohydrates for kernel filling compared to kernel from without fertilizer application.

The storage protein in the maize kernel increased concomitantly in response to N and P fertilization at each stage of maturity suggesting that protein formation is positively related to nutrient uptake from the soil. The composition of assimilates channelled to the seed by the mother plant influenced the balance of C and N in the endosperm. Total maize protein consists of a mixture of prolamins, glutelins, albumins, and globulins. Since, the level of prolamins which increase in endosperm during kernel maturation is used to assess the total protein quality in maize (*Nuss and Tanumihardjo* 2010). The gradual increase in protein at milk stage (18 DAS) under optimal fertilizer application could be explained by the fact that nitrogen and phosphorus enhanced the growth of maize kernels by regulating the synthesis of starch and protein in the endosperm. While, maize kernel grown under poor soil nutrition have limitation in conversion of sucrose and protein into precursors for starch synthesis as observed in kernel under no fertilized conditions. *Blumenthal et al.*, (2008) indicated that concentration of the protein in maize kernel was closely associated with the level of soil nutrition. Though, nitrogen application increases grain protein concentration, but has a negative effect on maize grain amino acid. The largest percentage of the total protein uptake is stored in maize kernel at dent stage (42 DAS) during 2014/15 warmer season while the largest protein content was in kernel harvested physiological maturity during 2015/16 drier season. This could be attributed to the fact that high atmospheric temperature forced early accumulation and maturity in the kernels during 2015/16 while the favourable weather conditions during 2014/15 season enhanced and prolonged the rate of nutrient accumulation. Similar observation was explained by *Bita and Gerats* (2013) that increase in temperature above the optimal might cause kernel not to reach maximum

starch and protein accumulation. Early harvested seeds at milk stage (18 DAS) were immature, poorly developed and has poor storage for nutrients compared to seed harvest at physiological maturity. *Khanduri et al.*, (2011) reported that maturation is at its peak for simple sugar accumulation around 28 days after pollination and is converted to starch for the final growth in the kernels.

Proline influenced seed development in maize, increase in proline accumulation in kernel under no fertilizer treatments indicated the connection of proline to the glutamate–glutamine metabolism which helps in nitrogen remobilization efficiency and prematurely induced by soil nutrient deficiency (*Mattioli et al.*, 2009). This study shown that proline content varied in the kernel obtained from different locations and seasons. Similar finding was reported by *Špoljarević et al.*, (2011) that the growing year had a very significant effect on the free proline content in the plant and enzyme activities assayed. The increase in proline content with kernel maturity showed its strong associated with seed development (*Mondo et al.*, 2013). *Nuss and Tanumihardjo* (2010) explained that endosperm which constitute 83% of the kernel is the source of proline accumulation and might increase up to 20% of the total nitrogen in the endosperm. This study indicated fertilizer application enhanced the free amino acid (proline content) in the kernels and reduced with application of recommended fertilizer rate.

Conclusions

The stage of maturity at harvest and soil fertility level had great impact on nutritional composition of maize kernel. This study showed that increasing rate of fertilizer had direct effect on the kernel nutrient accumulation as well as the duration of maturity stage at harvest is also of great importance. Stressful conditions (2015/16 season) during seed development reduced the seed weight and indirectly the seed food reserves while application of fertilizer during this period had little effect on the food reserve capacity. Improving soil fertility level during maternal plant growth and

development could not compensate for maximum total protein and starch accumulation in kernel obtained at dent stage. Physiologically matured kernels with minimal fertilizer application had little or no differences in their starch and protein contents. However, not adherence to the recommended fertilizer rate in early harvested kernel, which has not attained physiological maturity, resulted in lower photo-assimilate. Though, kernel harvested at 42 DAS (dent stage) performed second best with regards to all nutrients content studied. The soil fertility level of the mother plants during seed development and stages of maturity at harvest influenced seed nutrient composition, which in turn may affect its performance in the next generation.

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GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

Production of crop with high yield and quality is challenging with the continuous variation in climatic condition and nutrient depleted soils (*FAO* 2015). These challenges were more severe among rain fed or resource poor farmers in sub-Saharan Africa's drylands. Efforts towards resilient and efficient agricultural production through management practices that will mitigate the negative effect of current climatic changes has been considering. The realistic option under the current scenario is to master the management techniques and the environmental conditions. The most important management decision for high crop production is the availability of good quality seeds of high yielding varieties, soil fertility, and time of planting date and maturity stage of the crop at harvesting. The synergetic effect of these management practices was believed to improve the production and quality of crop especially maize during this period.

The studies presented in this thesis were based on the hypothesis that environmental factors that influence seed development and maturation can determine the seed's yield, viability and vigour (Tekrony, 2003). This study hypothesised that the combined effect of the management factors during maize hybrid growth and development will enhance its seed production and quality during adverse weather conditions among resources poor farmers. It was further hypothesised that nutritional content of the crop could be altered by the environmental conditions of the maternal plant. To test these hypotheses, field and laboratory experiments were conducted. Field experiments evaluated the interactive effect of different planting environments, seed maturation and different soil fertility status on physiological responses, growth, yield and yield components content of a commonly grown maize hybrid among the Southern Africa farmers under rain-fed conditions. The

laboratory experiment evaluated germination capacity and vigour of the harvested seeds under each management conditions as well as its nutritional composition.

The current climatic change pose additional challenge to maize production through extreme weather conditions leading to uncertainty in planting date. Meanwhile, the wide environmental adaptability of maize as it can be grown in regions with less rainfall of 250 mm and high rainfall of 5000 mm at sea level to 4000 m altitudes (*Duncan 1975*), make it an important crop during this period. Rainfall and temperature indices are key parameters that influence the decision of planting date. Therefore, variation in the environmental conditions was carried out at three different planting dates during two seasons. Early planting was carried out when there was adequate soil moisture and optimal temperature (28°C) to support the growth of the crop, which occurred around mid/late November South Africa.

During the first planting (2014/15) season, the reproductive stage of maize planted earlier experienced adequate rainfall and optimal temperature followed by those maize in mid planting date. However, the seed developmental stages in lately planted maize coincided with the period of erratic rainfall and drop in atmospheric temperature. Similar, scenario was observed in the second planting (2015/16) season for late planted maize. However, mid planted maize received optimal temperature compared to early-planted maize. Varying environmental conditions through different planting dates had significant effect on plant ecophysiology, growth and yield.

Nutrient uptake through fertilization was more effective during favourable growing conditions. The plant growth and physiological parameters measured had the highest performances at optimal fertilized conditions under 2014/15 season as reported in (chapter 3A). Plant height increased slowly in drier (2015/16) season and as well as in late planting due to detrimental effect of dry spell on height increment. Likewise, low rainfall might have caused water deficit conditions, which adversely affected number of leaves and leaf area and hindered the efficiency of leaf area to

intercept light. The rise in leaf temperature caused by high atmospheric temperature under stressful conditions (2015/16 season) might have inhibited the enzymatic activity and reduced the plant photosynthesis. *Anjum et al.*, (2011) attributed the decrease in photosynthetic rate under stressful conditions to dehydration of mesophyll cells, which altered the activities of enzymes involved in the mechanism of photosynthesis, and changes in gas exchange characteristics as well as causing reduction of plant water use efficiency. Optimal temperatures and frequent distribution of rainfall in 2014/15 season enhanced fertilizer application response by reducing leaching and enhancing adsorption which was contrary in 2015/16 season (*McNeill et al.*, 2005). Environmental conditions during the season influenced crop nutrient requirements and uptake. Grain yield, thousand seed weight and kernel row/ear were majorly affected by climatic conditions and soil fertility. Thus, the magnitude of variation in mobilization of seed reserves vary in different planting dates particularly with extreme temperature and rainfall. While the effectiveness of fertilization was higher during warmer than during drier season. *Haruna and Nkongolo* (2013) attributed variations in grain yield to differences in agro-ecological conditions, degree of variability of seasonal rainfall, length of growth period and land use.

Grain yield, ear length, ear diameter and thousand seed weight were mostly affected by the interaction of maturity stage at harvest and planting dates as reported in (chapter 3B). Thousand seed weight obtained at dent stage (42 DAS) under moderate and favourable weather conditions performed higher than its counterpart from physiological maturity (58 DAS) which experienced adverse weather conditions (late planting) during its growth and developmental stages. This gave the possibility of obtaining reasonable yield when harvesting occurred at dent stage. Harvesting too early at milk stage (18 DAS) during extreme weather conditions lead to high yield loss due to low nutrients accumulation as expressed in low thousand seed weight and grain yield except if it meant for silage production. This current research agreed with *Modi and Greenfield* (2010) who reported

that reduction in grain yield experienced with extreme weather conditions was due to an increase in the duration of the grain-filling and decrease in the rate of grain filling which were insufficient to prevent grain yield loss. The improvement in grain yield of the early and mid-planted maize might be due to the increase in plant growth under adequate rainfall. This enabled the plant to reach post-anthesis stages during the hottest summer periods and escaped greater water deficit stress compared with later planted maize where its nutrient availability, uptake, transport and grain filling coincided with extreme temperatures and water deficit.

The soil fertility status experienced during the maize growth and development has a modifying effect on its seed production as observed from the two experimental sites used and reported in (chapter 3C). The two sites (Ukulinga and Baynesfield) used in evaluating the effect of soil fertility levels and maturity stages at harvest were of different bioresource groups/agro-ecological areas. Ukulinga Research Farm is semi-arid while Baynesfield belonged to humid climatic zone. Ukulinga site received mean annual rainfall lower than Baynesfield site.

High soil fertility status at Baynesfield site coupled with high distribution of rainfall enhances the plant growth and physiological development as compared with Ukulinga site. Optimal fertility levels helped to improve the rate of photosynthesis and stomatal conductance. Reduced plant height, leaf number and leaf area index under none fertilized treatments might have been an adaptation strategy to minimising water loss during water stress period (*Mabhaudhi and Modi* 2011). Similar results showing reduction in maize plant height, leaf number and leaf area index were found in the literature (*Efthimiadou et al.*, 2010, *Faheed et al.*, 2016). Also, the similarity in grain yield obtained from optimally fertilized dent stage with those harvested at physiological maturity under no and minimal fertilized conditions indicated the importance of adequate soil fertility status on the grain filling period which might have increased the rate of assimilate in the kernel as observed. *Bender et al.*, (2013) reported that maximum rates of dry weight production occurred between V_{10} and V_{14}

and between R₂ and R₄, which coincided with the maximum measured rates of nutrient uptake. In the presence of abiotic stress, harvesting a stress-free optimally fertilized maize at dent stage will maximize the yield potential of a crop and be the best option than to allow the maize to reach physiological maturity under poor soil fertility status or adverse weather conditions

In addition, environmental variation during seed development and maturation caused variation in the germination percentage of the progeny seeds harvested at different planting dates as indicated in (chapter 4A). Progeny seed harvested at dent stage under early and mid-planting dates during warmer and drier seasons respectively showed some promises in germination capacity in such that it performed at par with those from physiological maturity. This might be due to the favourable weather conditions experienced. During dent stage (R₅) of maize seed, some of the essential seed components and physiological attributes might have been attained which could have attributed to its seedlings vigour. Since, seed accumulates most of its dry weight during dough development (Zečević *et al.*, 2006) which facilitates seedling viability and vigour, thus seed harvested at dent stage exhibited some level of vigour. Though seeds harvested very early in its developmental stage (milk stage) were capable of germination because embryo maturity occurred earlier during development but their germination capacity is very low compared to seeds that reached physiological maturity. In addition, progeny seeds from physiological maturity under extreme weather conditions (late planting) expressed poor germination and vigour.

Seed harvested under optimally fertilized trials and suitable weather conditions had high germination performances and vigour than those under extreme weather conditions as indicated in (chapter 4B). This could be attributed to higher photosynthates accumulation and the presence of optimal temperature and rainfall during the crop growth and development stages. This study confirmed the observation of Carson and Ozores-Hampton (2014) who explained that the patterns of nutrient release through fertilizer application were greatly affected by temperature, moisture, and

other conditions that altered biological activity. However, application of fertilizer during unfavourable environmental conditions as observed in late planting had no positive effect on the quality of seed produced.

Stage of maturity at harvest and fertility level significantly determined the germination characteristics and vigour of maize seed as reported in Chapter 4C. Delay in harvesting gave more space to accumulation of assimilate and reduced the seed moisture content. Thus, physiologically mature seeds had the highest germination percentage. It was noteworthy that seedlings under optimal fertilization from dent stage performed similarly in daily germination and vigour index with physiologically mature seeds. It performed second best in germination velocity index and mean germination time with seeds from physiological maturity. This could be attributed to application of optimal fertilizer to the mother plants, which enabled it to accumulate photosynthates faster and supply high energy for the enzymatic processes involved during the germination. In addition, maize seed acquired the ability to germinate as early as 35 days after pollination as observed among seedlings from milk stage but were unable to attain maximum germination (*Oishi and Bewley 1990, Wang et al., 2016*). The increase in seedling mass and thousand seed weight of seed lot obtained at dent stage and physiological maturity showed that advancement in harvesting coupled with optimal fertilization allowed accumulation of more assimilates to the developing kernels. This study showed that planting location and season had strong impact on the germination characteristic and vigour of the seed harvested at dent stage and physiological maturity stage than at milk stage

The seed food reserve (thousand seed weight) at each season varied, the reduction in seed weight during 2015/16 compared to 2014/15 season might be due to the presences of high atmospheric temperature and erratic rainfall experienced. These negatively influenced assimilate production and its translocation to developing seeds. The main nutrition of the developing seed is provided by photo assimilates (sugars, amino acids, and other solutes) translocated via vascular tissues and by

available nutrients absorbed from the soil. Moreover, sugar accumulated at each maturity stages varies in concentration. Fructose and glucose were more pronounced while sucrose was little concentration in kernel from milk stage but the concentration of glucose and fructose decreased while sucrose increases from milk stage to physiological maturity. The conversion of sugar into starch increased from milk stage to physiological maturity in the kernel. This study found out that improving the soil fertility level enhanced the rate of sugar accumulation and conversion to starch even for kernel harvested earlier before attaining maturity. The gradual increase in protein at milk stage (18 DAS) under optimal fertilizer application could be explained by the fact that nitrogen and phosphorus enhance the growth of maize kernels by regulating the synthesis of starch and protein in the endosperm. Though, physiologically matured kernel with minimal and optimal application of fertilizer had little or no differences in protein accumulation obtained from the kernel.

CONCLUSION

This study provides evidence that the distribution of rainfall at each season had a strong influence on nutrient utilization for plant growth and yield production. Stronger responses to N and P fertilization occurred in warmer season where temperatures were optimal and rainfall was evenly distributed. However, fertilization had little effect on the kernel nutrient compositions during the drier season. Hence, minimal application rates of fertilizer during drier season gave similar yield output as optimal application.

In addition, this study has showed that high seed quality in maize can be attained by planting early during warmer season but mid planting date will give the maximum seed quality during drier season. The stage of seed maturity at harvest is an important decision to be considered before harvesting especially during extreme weather conditions. Application of N and P fertilizer improved seed quality at each planting date under warmer season but had no positive impact on the quality of seed produced during late planting especially under drier season. Minimally and optimally fertilizer application enhanced the seed quality under favourable environmental conditions. Thus, farmers can still obtain high seed quality with minimal fertilization provided there is favourable weather conditions. Though, physiologically mature seeds under optimal fertilizer application had maximum acquisition of seed germination and vigour. However, in the case of adverse weather condition or infestation of diseases and pest seed lots harvested at dent stage (42 DAS) under optimally fertilized conditions would still gave higher quality seeds than expose the cobs to the harsh conditions which lead to total seed loss. It was evident from this study that none adherence to the recommended fertilizer rate and early harvest before the attainment of physiological maturity resulted in lower photo-assimilate in kernel harvested. Though, kernel harvested at 42 DAS (dent stage) performed second best with regards to sugar, starch and protein content in the kernel. The soil fertility level of

the mother plants during seed development and stages of maturity at harvest affected seed nutrient composition, which in turn may affect its performance in the next generation.

RECOMMENDATIONS

- From the findings of this study, it was recommended that future studies should be conducted on interactive effect of planting dates, maturity stage and harvest and soil fertility under different irrigation systems.
- The field experiments on planting dates in combination with other management practices need to be repeated using more maize hybrids cultivars under different planting sites so that variation can be inferred. In addition, the crop science experimental lands in the university research farm (Ukulinga) should be well fenced to prevent the invasion of wild pigs for subsequent or future trials.
- The use of molecular marker to investigating the nutrient accumulation in maize under different management practices in relation to different environmental conditions and the development of seed quality.
- Study on the role of seed priming on early harvested seed meant for next planting generation under different management practices may provide a much better understanding in relation to seed quality development.
- Future studies should evaluate the acquisition of seed quality for seed planted at the different planting dates under irrigation system.

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