Planting date effects on growth, development and yield of selected agronomic crops at Makhathini Irrigation scheme

by

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PREFACE

The research contained in this thesis was completed by the candidate while based in the Discipline of Crop Science, School of Agricultural, Earth and Environmental Sciences, in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa.

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

Signed: Professor Albert T. Modi

Date: 21 November, 2014

DECLARATION

I, Walter Tom, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) this dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) their words have been re-written but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

(vii) this dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

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Signed: Walter Tom

Date: 21 November 2014

ABSTRACT

Agriculture, as a source of rural livelihood, is currently faced with challenges such as increasing temperatures, floods, and drought frequency associated with climate change and variability. Climate change is associated with shifting rainfall patterns and distribution, thereby affecting the conventional planting dates. Seasonal variability of rainfall, through uneven distribution and variable amounts, places subsistence farmers at greater risk as they are unable to cope. Simple decision making strategies such as choice of planting date and crop selection could help farmers mitigate some of these impacts. Therefore, the objective of this study was to evaluate the effect of planting date selection on growth and yield of three crops, namely, maize (cereal), dry beans (legume) and sweet potato (root crop). Four planting dates were selected starting from November, 2013 through to February, 2014 and field trials were established at Makhathini Research Station, Northern KwaZulu-Natal. The choice of planting date significantly impacted on growth and yield of crops, especially during critical developmental stages where crops needed sufficient water and optimum temperatures. Dry mass accumulation was greater in the first planting date followed by the third planting date and lastly the second planting date. Water and heat stress were not the only climate characteristics affecting crop growth and yield of all the crops. Flash floods led to significant yield losses, and in some cases, crop failure. Based on the results, planting date selection can be used as a management tool for managing water stress under rainfed conditions. Optimal planting dates varied for the different crops. Maize performed better in the first and third planting dates. Sweet potato was successful only in the second planting date although there were no marketable storage roots. Sweet potato showed high sensitivity to water stress and high temperatures particularly during early establishment and vegetative phases. Dry beans performed better during the fourth planting date. The findings suggest that the crops can be planted at different times of the season. This can improve household food security through broadening on-farm diversity and spreading the risk of crop failure.

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DEDICATION

This thesis is dedicated to my mother, Miriam Kutsonga, son Herbert and daughter Ingah Tom who inspired me.

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CHAPTER 1

INTRODUCTION

1.1 Introduction and Rationale

Agricultural productivity is believed to be under threat due to global climate change (IPCC 2007). This is predominantly so in developing countries where the impacts of climate change are felt especially amongst the rural communities. Agriculture as a source of livelihood is partly faced with challenges such as excessive heat, floods and drought caused by climate change (Matarira and Mantasa. 2009). Africa depends greatly on rain-fed agriculture hence the economic vulnerability is higher than that of the developed world (Parry *et al*. 2001). The degree of risk in African countries is worsened by the unavailability of funds to develop climate change adaptation strategies (Fischer *et al*. 2005). Their vulnerability to climate change comes both from being located mainly in the tropics, and from the various socioeconomic, demographic, and policy trends limiting their capacity to adapt to the changes.

South Africa, being part of the Southern African community is not unique; the majority of the poor (72%) are situated in such areas where they depend on dry land farming (Ortmann and Machete. 2003). According to Davis (2008), challenges in subsistence farming are imposed by the perpetual risk caused by seasonal variability of rainfall through both uneven distribution and variable precipitation quantities in South Africa. The vulnerability to a range of climate change stressors is exacerbated by the intrinsic nature of their farming environment and the complexity of the location specificity which makes standardised recommendations on climate adaptation strategies difficult.

Subsistence farming, as a low input and mostly rain-fed farming system, is threatened by climate change. More so, most subsistence farmers are situated in marginal areas where poor yields may occur in consecutive seasons leaving them economically poorer (Mutekwa 2009). The greater rural population of South African farmers derive income from rain-fed agriculture, of which crop yields are anticipated to decrease due to climate change impacts (Ellis 2000, Downing 1992).

One of the challenges brought about by climate change is believed to be the shifting of rainfall patterns and distribution (Droogers *et al*. 2001). The rainy season either states early or much later than the traditional dates that subsistence farmers have been accustomed to. This has challenged subsistence farmers' traditionally known planting dates. In most cases, farmers still plant early, only for the rains to come later often resulting in massive crop failure, something most subsistence farmers lack the resources to recover from (Mabhaudhi *et al*. 2014). This therefore threatens the resilience of their cropping systems. The choice of planting date and crop to grow becomes a challenge to the subsistence farmer. Some subsistence farmers have even reduced planted area due to high crop failure.

1.2 Justification

Subsistence farmers rely on knowledge of previous seasons' planting dates, observations of natural vegetation changes together with the first effective rainfall by either dry planting before or after the rainfall. Some farmers split planting or stagger within one season to avoid absolute risk (Traore *et al*. 2007, Lemos and Dilling 2007). The shifting rainfall patterns due to climate change affects the forecast based on such traditional meteorological knowledge as these lack detail and accuracy, resulting in compromised credibility (James *et al*. 2011).

The shift in planting dates also implies that some crops that have been traditionally cultivated by the farmers may no longer be suited to the new season durations. As such, there is also a need to diversify the crop base utilised by subsistence farmers as an effort to increase on–farm agro–biodiversity and resilience. Strategies to achieve this should also pay attention to challenges of food and nutritional insecurity that persist in rural households. This suggests that any new crops suggested should be nutritious crops that can address protein and mineral deficiencies. In addition, such crops should have high yield potential such that farmers may transition from subsistence to semi-commercial farmers. This will aid in efforts to achieve Millennium Development Goal 1(UN Millennium Development Goals Website).

The choice of planting dates could significantly impact on growth and yields of crops, particularly during the critical development phases where plants require adequate moisture and ideal temperatures at planting, seedling establishment, flowering and fruit formation (Passioura 2007). Poor planting date selection may subject crops to water and heat stress during dry spells at critical growth stages resulting in reduced yield. In order to minimize farming risk, a need arises to ascertain planting dates and good crop choices among subsistence farmers.

1.3 Aims and Objectives

This study seeks to contribute to addressing the problem of yield loss and crop failure due to uninformed planting date selection practices among subsistence farmers of

Makhathini rural district, KwaZulu–Natal, South Africa. The study area of Makhathini was selected as a study area as it is predicted to experience climate change and variability hence affecting food security of vulnerable farmers. While some farmers in Makhathini rely on the irrigation scheme, a majority still rely on rainfed agriculture. The study explores the planting time which provides the most economic yield outputs and that could form part of the strategy for staggering the planting of various dry land crops. The commonly grown crops among subsistence farmers in this area (maize and sweet potatoes and dry beans) will be explored in this study. The selection of crops was based on commonly cultivated crops within area; further consideration was given to represent a cereal, legume and root crop with a view to contributing towards improved nutrition within the community. The aim of the study was to determine the effect of planting dates as a drought management tool, on growth, phenology and yield of the three crops. It was hypothesized that choice of planting date does not have an effect on growth, phenology and yield of sweet potatoes, dry beans and maize.

The specific objectives of the study were:

1. to determine the effect of planting date (Nov, Dec, Jan and Feb) on growth, phenology and yield of maize under rainfed conditions;
2. to determine the effect of planting date (Nov, Dec, Jan and Feb) on growth, phenology and yield of sweet potatoes under rain-fed conditions; and
3. to determine the effect of planting date (Nov, Dec, Jan and Feb) on growth, phenology and yield of dry beans under rain-fed conditions.

CHAPTER 2

LITERATURE REVIEW

2.1 Maize

2.1.1 Origin and history

Maize (*Zea mays*) (Fanadzo *et al*. 2009) is also known as umbila in IsiZulu, cingoma (seTswana), mahea, majs (seSotho), mielies (Afrikaans) and chibage or chibere in Zimbabwe (Kay. 2011). It belongs to the grass family (Poaceae), tribe Andropogoneae and genus “Zea” (Zela) which is a derivative term from the Greek name for food grass. Other species are referred to as teosintes, tripsacum and coix which are wild species closely related to domesticated maize. The wild species are unique to domesticated maize due to them being found in restricted and contrasting ecological sites (Hufford *et al*. 2012). It originated from the Americas around Mexico in the Mesoamerican region. Archaeological records and phylogenetic analysis suggest that domestication began at least 4 000 – 10 000 years ago (Matsuoka 2005). Maize is believed to have been brought into Africa by the early Portuguese sailors who probably had trading motives on the continent in the 17th Century (Miracle 2009). Due to maize growth under diverse environments and storability it rapidly spread to almost every province replacing sorghum (*Sorghum bicolour* (L.) Moench) and millet (*Eleusine coracana* Gartner) becoming the staple food such that approximately eight million tonnes are produced yearly in South Africa (du Plessis 2003). According to Ofori and Kyei-Baffour (2004), in sub-Saharan Africa, maize is the main food which provides 50% of basic calories to 50% of the population.

2.1.2 Botany and ecology

The classification of maize is centred on the characteristics of the cob and kernels by Eubanks (2001), while Matsuoka (2005) classifies maize according to the structure of the tassel and spike. Maize is a monoecious grass which can grow to as tall as 4 metres. The morphology is characterised by the female inflorescences which develop in leaf axils on the stalk which terminates in the tassel (Figure 2.1). A maize plant produces large, narrow, opposite leaves borne alternatively along the stem. Maize is an annual grass which is 5% self–pollinated and 95% cross pollinated by wind. Maize generally flowers between 55 to 60 days and matures in about 115 days and in some areas may be grown all year round because of the availability of many different hybrids suitable for varied conditions. The vegetative stages in maize may be summed up as the seeding or sprouting, grand growth and tasseling or flower initiation phases.

The ideal temperatures for maize seed germination are between 20ºC and 30ºC, while soil water content should be about 60% of field capacity (du Plessis 2003). The reproductive stage is also in three distinct phases namely, the silking phase, soft-dough or milky phase, and the hard-dough or maturity phase. The maturity phase is when the leaves and silk have dried completely and become brittle (Birch and Vos 2000). Maize kernels vary in shape, colour and size depending on varieties. The kernel is made up of endosperm, embryo, pericarp and tip cap (Figure 2.2). The grain kernels may be commercially classified as dent, flint, flour and waxy corn (Magness *et al*. 1999). The dent kernel consists of two flat sides while the flint kernel can be round or flat in shape.

Maize grows in a wide range of environments, including the tropics, subtropics and temperate regions. Yield potential differs according to geographical location because radiation, temperature and rainfall conditions vary (Birch *et al*. 2003). Yield is also greatly dependent on soil fertility, plant population management, altitude and air temperature, occurrence of pests and diseases, cultivar choice and planting time (Fanadzo 2007). Maize yields at present in Africa range between 1.5 to 1.8 tonnes ha^{-1} while in America yield exceeds 7 tonnes ha^{-1} (FAOSTAT 2013). The average maize yield obtained under small-scale production in the Eastern Cape, South Africa was 1.8 tonnes ha^{-1}. Southern Africa is considered the highest consumer of maize (85 kg $capita^{-1}$ $year^{-1}$) when comparing with East Africa which stands at 27 kg $capita^{-1}$ $year^{-1}$. Maize generally covers 25 million hectares in sub-Saharan Africa with an output of 38 million metric tonnes (Smale *et al*. 2011). Wada (2008) projected that the global demand for maize will rise from 558 million metric tonnes to 837 million tonnes by 2020.

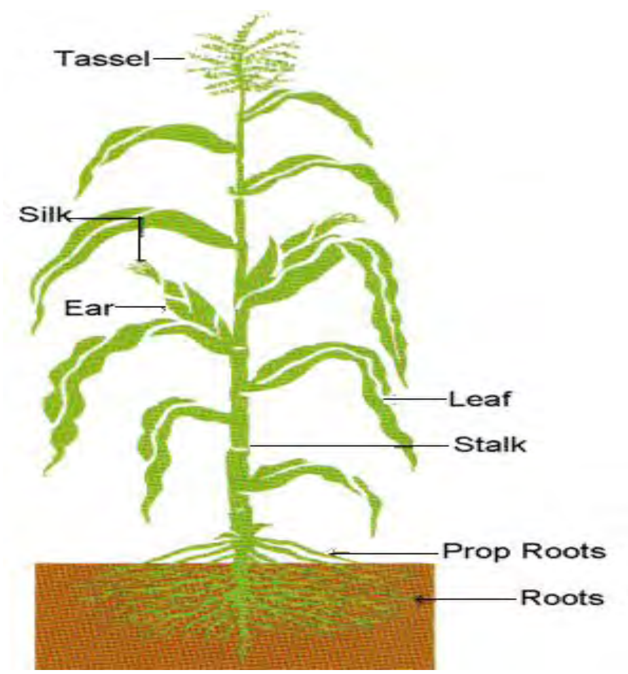

Figure 2.1: Morphology of the maize plant (Source: http://www.jonesfamilyfarms.wordpress.com/2011/7/2011/sweet-corn). Accessed: 16 August 2014.

Figure 2.2: Main maize kernel components. (Source: http://www.bealldeg.com/introraw.html). Accessed: 16 August 2014.

2.1.3 Importance of maize

Maize plays a major role in food security especially in Southern Africa. It is a major staple food in the form of mealie-meal, samp, mealie-rice or as boiled or roasted on the cob. Maize seed contains crude protein (9.6%), crude fibre (2%), carbohydrates (70.8%) and micronutrients recommended by the World Health Organisation (George *et al*. 1989). The traditional social-cultural use of maize is for making alcohol for rituals and social gatherings in rural areas. Maize, as the staple crop in most sub-Saharan countries, gives the largest output per man-hour spent on it than any other crop (Mashingaidze 2012). Maize per-capita consumption in Southern Africa is the highest in the world, hence the need for high maize productivity in the region. It is a water use efficient crop suitable for rotations with legumes and also intercropping in water stressed environments which make up most of the maize production areas in southern Africa (Department of Agriculture 2007). Intercropping maize and molasses or Sudan grass provides natural control of stemborers and increases parasitism (Khan *et al*. 1997).

Maize is a cash crop with several economic uses in the world. In South Africa, it can be processed into drinks, mealie-meal, breakfast cereals, cooking oil, stock-feeds, starch, maltodextrins, maize syrup as well as products of fermentation and distillation industries (JAICAF 2008). Corn starch, corn syrup and dextrose are used in manufacturing vitamin C and penicillin in the pharmaceutical industry (Ofori and Kyei-Baffour 2004). Maize is also used in making additives in paint, explosives, biodegradable chemicals and plastics (Ofori and Kyei-Baffour 2004). The wet and dry milling industries process maize kernels to samp, maize grit, maize rice, unsifted, sifted, course and super maize meal. Starch is extracted during wet milling process after which residues such as germ, gluten, husks and steep water are used to produce stock feeds (Block *et al*. 2005, Boddugari *et al*. 2001)). The feed industry supplies about 60% of the total stock feeds consumed in the livestock industry and the poultry industry is the major consumer at 60% (1 386 000 tonnes) (Klopfenstein *et al*. 2012).

Maize constitutes 55% of the 4.2 million tonnes of stock feed produced in South Africa (Statistics & Analysis DAFF 2012). The production of maize in Africa stands at 71 million tonnes (7% of world production share) while South Africa as a key producer contributes 12.3 million tonnes (17.3%) of the continent's total production (FAOSTAT 2013). The world's leading producer of maize is the United States of America at 274 million tonnes per year. Ofori and Kyei-Baffour (2004) mentioned that about 4 000 industrial products were made out of maize in the world and in the USA supermarkets alone carry 1 000 items which contain maize. Maize is a substantial foreign currency earner for South Africa (Du Plessis 2003). The value of maize exports in 2010 stood at R1.8 billion (Statistics & Economic Analysis DAFF 2012).

2.2 Dry beans

2.2.1 Origin and history

Dry beans (*Phaseolus vulgaris*) originated along with maize in Mexico, Central and South America over 7 000 years ago (Myers 1999). The family of the Dry beans is Fabaceae, sub-family Papilionoideae and genus *Phaseolus sensu stricto*. Within the genus *Phaseolus*, there are three species which are agronomically important in South Africa (Manjeru *et al*. 2007). These are *Phaseolus acutifolius* (Tepary beans), *Phaseolus coccineus* (large white kidney beans) and *Phaseolus vulgaris* (dry or common beans) (Liebenberg 2002; Manjeru *et al*. 2007). However, large seeded lima beans are classified as tender perennials, but they are grown as annual crops. The genus *Phaseolus* is now planted around the world and in different cultivars, such as, common green beans, kidney beans, french bean, runner bean, black beans, among others (Manjeru *et al*. 2007). Within each species there are many seed types which differ in size, shape and colour. In each type there are different cultivars and the seeds of these cultivars differ very little from one another. However, considerable differences may occur in adaptability, growth habit, disease resistance and many other characteristics (Schwartz *et al*. 2004).

It was grown mainly as a source of protein and 55 species of bean are known. The largest producer of dry beans is Latin America at about 50% capacity of the world market followed by Africa at 25% (Beebe *et al*. 2013). Dry beans is currently grown in many regions including northeast Brazil and southern Africa where water stress frequently occurs thereby putting to test the genetic diversity for drought response (Williams *et al*. 2007). Kenya being the largest producer of dry beans in the region, the per capita consumption annually can be as high as 60 kg capita^{-1} year^{-1} (Beebe *et al*.

2013). Smallholder farmers traditionally dominated the production of dry beans in mostly intercropping cropping systems in rotation with maize, sorghum or other crops particularly in Africa (Broughton *et al*. 2003). The leading world producer of dry beans in 2013 was Myanmar at 3.8 million tonnes a year. Dry beans production in Africa amounts to 4.9 million tonnes while South Africa stands at 48 000 tonnes (0.9%) of the continent's aggregate production status (FAOSTAT 2013). South Africa exports approximately 25 000 tonnes per year while import amounts to 75 000 tonnes (Statistics & Economic Analysis, DAFF 2011).

2.2.2 Botany and ecology

The flowers are hermaphroditic, have both the stamen and pistil on the same flower, which enables self–fertilization. However, this floral morphology has the disadvantage that it may lead to diminishing genetic diversity. However, hybridization occurs frequently in nature due to this characteristic, as any plant can pollinate another due to the hermaphroditic properties enabling the pollination process from one plant to another (Gepts 1998). The crop has four major growth stages starting from emergence until maturity (Schwartz *et al*. 2004). The first growth stage is emergence (elongation of hypocotyl through the soil and then straightens out with unfolding cotyledons), and early vegetative growth (Figure 2.3). Secondly the branching and rapid vegetative growth, whereby branches develop on the leaf axes and rapid growth occurs as new nodes develop on the main stem and on branches (Figure 2.3). Thirdly, the flowering and pod formation occurs. Lastly, pod fill and physical maturity take place, and at this point 80% pods have changed colour. Growth habit of the bean species is categorised into three:

the determinate or bush type, the indeterminate compact upright and the indeterminate runner type (short runners) habits. *Phaseolus vulgaris* is categorised under determinate growth habit.

Dry beans grow in subtropical and dry tropical zones, so it does well in warm climates with average temperatures ranging between 18 and 24°C. Temperatures exceeding 30°C during flowering, might cause flower abortion (Stephen *et al*. 2014). The crop performs well in the tropics at an altitude of about 1 250 m with rainfall ranging from 400 to 650 mm. Beans grow well in deep (100 cm), well–drained soils with a pH of 5.8 – 6.5. The crop takes between 85 to 115 days to mature depending on cultivar and season, while the yield potential ranges between 1.5 to 2.5 tonnes ha^{-1} in South Africa (DAFF 2011). Wild bean has attracted the attention of researchers due to its genetic diversity and in-built mechanisms of repelling pathogens. It was also found to grow luxuriously at altitudes of 500 to 2 000 m.a.s.l and rainfall of 500 to 1 800 mm in the northern Mexico and Argentina (Gepts 1998).

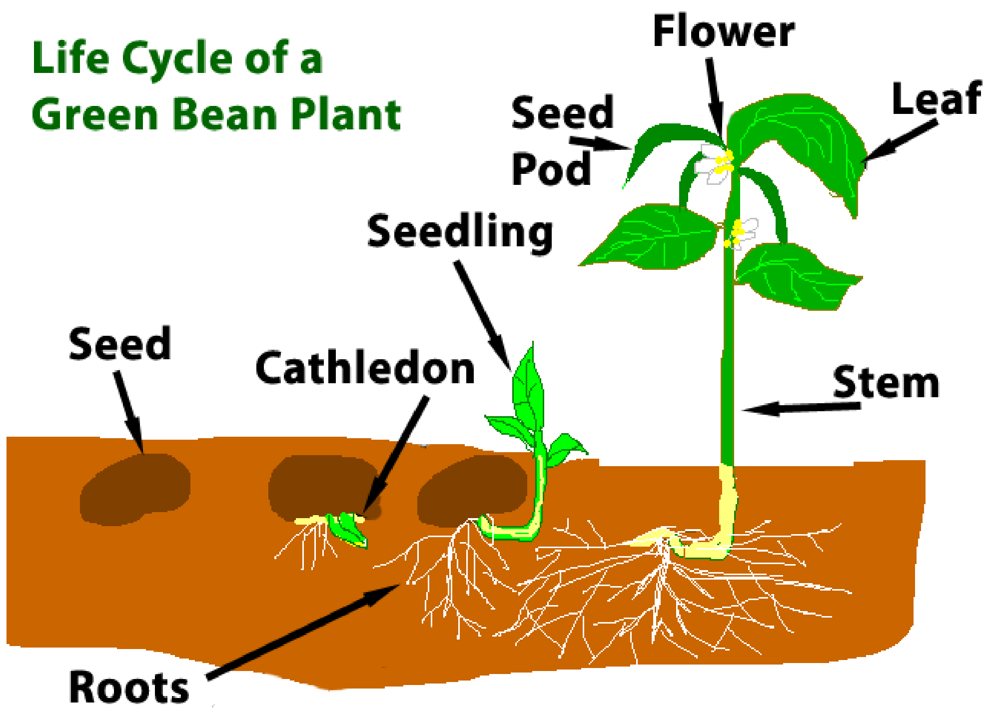

Figure 2.3: Life cycle and morphology of the bean plant (Source: http://pixgood.com/search.html) Accessed: 27 October 2014.

2.2.3 Importance of dry beans

Bean seed can be consumed raw or cooked, dried or boiled and it is one of the major food security crops in South Africa. It can be processed into flour or spices and oil (Halley and Taylor 1996). Dry beans is a high protein content crop which has the capacity to substitute meat as a protein source for resource lacking people (Sidik *et al*. 2005). In Africa beans occupy 40% of produced market value crops. An increase is likely as health organisations are encouraging its consumption as it decreases the risk of cancerous, diabetic and cardiovascular diseases (David *et al*. 2000). Dry beans contains crude protein (22.6%), crude fibre (4.2%), carbohydrate (57%) and micronutrients recommended for a good diet by the World Health Organisation (FAOSTAT 2013).

Dry beans is a leguminous crop, implying that it has the capacity to fix atmospheric nitrogen and does not require rhizobium inoculum at planting (Marco *et al*. 2006). This biological aspect makes dry beans a good fit in crop rotations and intercropping systems. The high producer prices for beans mean that it can be used as a cash crop, thereby alleviating poverty in poor rural households.

2.3 Sweet Potatoes

2.3.1 Origin and history

Sweet potato originated from north western South America where it is commonly called by names such as batata, camote, boniato, kumara and several others (Huaman 1992). In *IsiZulu*, sweet potato is called mbatata and mbambaira in Zimbabwe (Kay 2011). Linnaeus named the sweet potato species as *Convolvulus batatas* in the year 1753 and later in 1791 a botanist named Lamarck then classified sweet potato using stigma shape and surface of the pollen grains which then resulted in change of the name to *Ipomoea batatas* (L) Lam. Thirteen wild species are identified in same genus with sweet potato, among them *are I. grandifolia, I. tabascana, I. trifida, I. triloba, I. tiliacea and I. lacunose.*

Sweet potato was discovered by Christopher Columbus in Cuba and Hispaniola in the year 1492 and introduced the crop to Europe through Spain. The Portuguese traders introduced sweet potato to Africa from the Atlantic coast regions of America (Woolfe 1992). Africa on average produces 19.5 million tonnes of sweet potato which is 17.6% world production share and South Africa 56 000 tonnes which represents 0.3% of the total continent production (FAOSTAT 2013). The leading world producer is China standing at 78 million tonnes as of 2012 (Statistics & Economic Analysis, DAFF 2012).

South Africa exports about 1 683 tonnes of sweet potato per year which is 0.48% of world export and ranks at number 21 in the world according to Statistics and Economic Analysis of Department of Agriculture Forestry and Fisheries of South Africa (2012).

2.3.2 Botany and ecology

Sweet potato (*Ipomoea batatas*) is an herbaceous and perennial plant which is grown through vegetative propagation using storage roots or stem cuttings. The growth habits of a typical sweet potato plant are erect, semi-erect, horizontally spreading and widely spreading types. The root system of sweet potato is characterised by storage roots and fibrous roots which absorb water soluble nutrients and also provide anchorage to the plant (Huaman 1992) (Figure 2.5).

Depending on sweet potato cultivar, flowering varies from no flower, to few and to many (Figure 2.5). The flower is bisexual, containing the androecium and gynoecium. Pollination occurs usually in the mornings, facilitated by bees. The crop takes between 90 to 180 days to mature depending on cultivar and climatic conditions under dry land farming (DAFF 2011). Sweet potato is produced in the tropical climatic areas of the world, the leading countries being in Asia, including China, producing above 80% of the world crop (Titus 2008). In South Africa, the major sweet potato producing provinces are Limpopo, Mpumalanga, KwaZulu Natal and Western Cape. (Department of Agriculture, Forestry and Fisheries 2009).

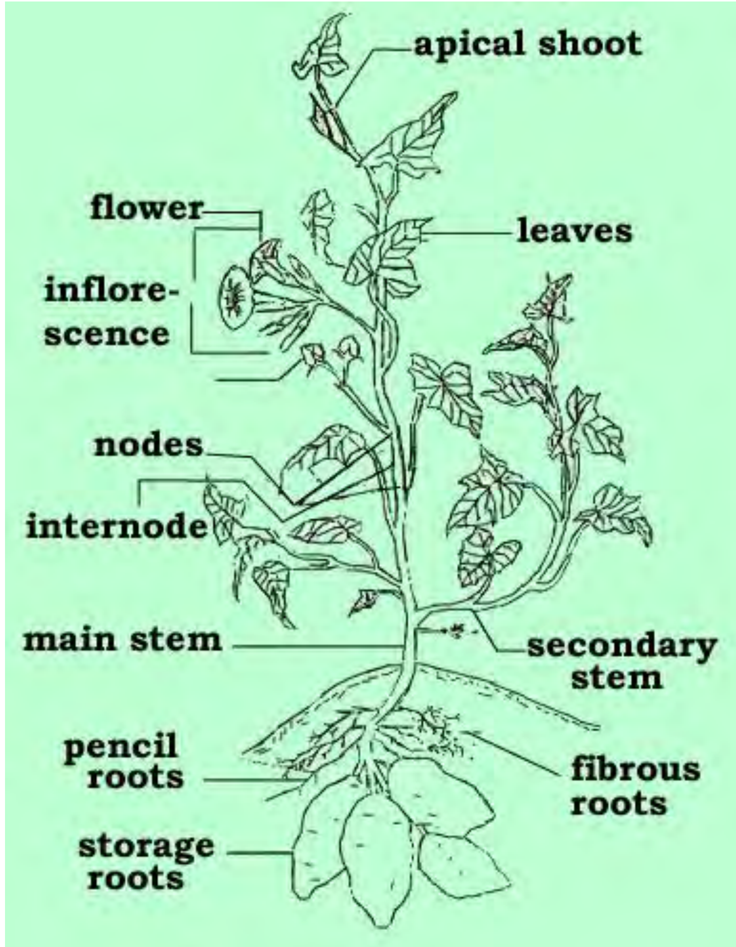

Figure 2.5: Morphological characteristics of a sweet potato plant (Source: http://keys.lucidcentral.org/): Accessed 27 October 2014.

2.3.3 Importance of sweet potato

Sweet potato can be made use of in several forms, with the tuber being consumed raw, boiled, as porridge or pounded into flour. Sweet potato varies in flesh and skin colour, texture, leaf shape and vine length. The orange flesh type sweet potato contains high vitamins A and C, and fibre, while vitamin B and minerals are found more in white fleshed type. The purple sweet potato contains more of antioxidants than vitamin A (Pleasant 2014). Sweet potato contains crude protein (1.5%), crude fibre (0.8%), carbohydrates (25.6%) and micronutrients essential for human health as recommended by the World Health Organisation (FAOSTAT 2013). The leaves are also consumed as vegetable relish. It is ranked as the third staple food in seven countries of Eastern and Central Africa after cassava and maize (International Potato Center 2013). It has a long shelf life of about two to three months which is advantageous for resource poor people who have no specialised food storage equipment (Wang *et al*. 1999). It is generally a high yielding crop (i.e. gives more tonnage per unit area of land) as compared to most crops grown by small-scale farmers in southern Africa. Sweet potato can be processed into starch for industrial products due to its high starch content. The vines or herbage is a source of high protein animal feed. Some of the products of sweet potato are flour, dried chips, juice, bread, noodles, candy, biodegradable automobile plastics parts, liquors and pectin (Srisuwan *et al*. 2006, International Potato Center 2013).

2.4 Plant Growth and Development

Plant growth is defined as the irreversible increase in mass that results from cell division and cell expansion (Anjum *et al*. 2011). Meristematic cell divisions give rise to daughter cells which result in growth through the multiplication of many young cells (Nonami 1998). Plant growth and yield traits are determined by the level of mitosis (Hussain *et al*. 2008). Plant growth contributes wholly to the increase of fresh and dry matter (Zhao *et al*. 2006). Development on the other hand is the sum of all changes that the plant goes through in its life cycle. It is as a result of growth and differentiation. Plant growth and development are controlled by three factors which are genetic control, hormonal control and lastly environmental stimuli (Xiong *et al*. 2006).

2.4.1 Factors affecting plant growth and development

In Africa major crop losses and reduction in crop yields are usually caused by extremes in environmental factors. Studies on effects of planting dates on crop growth and development reported that temperature and water were the most important environmental factors influencing success or failure of the cropping season (Tsimba *et al*. 2013). Subsistence farmers are the most affected as they lack resources to create micro-climate structures to counter temperature and water stresses (Coe and Stern 2011).

2.4.1.1 Temperature

Temperature is known to affect growth and development processes but optimum atmospheric temperature varies with processes. Seedling emergence and establishment are critical stages in crop production which when plants are subjected to either extremely low temperatures, germination may be delayed or extremely high temperatures seedling mortality can occur due to seedbed dryness caused by too much heat (Johnson and Asay 1993). Awal and Ikeda (2001) reported that the rate of peanut seedling emergence increased by approximately 1.4 calendar days for every 1°C rise in soil temperature. Temperatures may also have an effect on vegetative growth for example in maize.

Al-Darby and Lowery (1987) reported that low temperatures experienced during early planting resulted in shorter maize plants with fewer leaves. Temperatures below 18ºC and above 25ºC reduced leaf area index, in the same crop. A study in New Zealand showed similar result that temperature ranges of approximately 15 – 17 ºC under early planting conditions reduced leaf area index. Temperatures below 8°C or over 40°C may result in cessation of crop development (Fournier and Andrieu 2000).

According to Grant *et al*. (1989), grain yield is related to kernel number at harvest and it is a yield component which relies on the physiological condition of the crop during flowering. The latter has been observed by (Rattalino Edreira and Otegui 2013) where heat stress before silking reduced potential kernel number per plant than after silking. In maize, high temperatures reduced the period from silking to physiological maturity, speeding up leaf senescence thereby restricting grain formation resulting in low grain mass (Birch *et al*. 2003). Generally, when maize plants were grown under high temperatures there was a decrease in whole plant dry matter accumulation (Badu-Apraku *et al*. 1983).

2.4.1.2 Water

Water being one of the major requirements for plant growth and development can cause losses to crop yields if water deficits occur. The water deficit can be temporary or permanent severely hindering plant growth greater than any other environmental factor (Anjum *et al*. 2011). A crop can be affected by water stress when water becomes unavailable to the roots or transpiration rate exceeds plant water uptake rate which impacts negatively on growth, yield, membrane integrity, pigment content, osmotic adjustment, water relations and photosynthetic activity (Praba *et al*. 2009). Drought also creates a condition whereby plants cannot absorb enough mineral resources due to lack of water for solubility (Poorter and Nagel 2000).

In Papua New Guinea, the marketable sweet potato tuber yields were observed to be significantly correlated to rainfall thus the more rain the higher the yield (Alfred *et al*. 2000). Faba bean grown under adequate water produced higher pod yield (4.6 – 7.6 t ha^{-1}) compared to those grown under water deficit (1.4 – 5.4 t ha^{-1}) (Husain *et al*. 1983). They further reported that faba beans grown under water deficit were characterised by reduced rate of shoot elongation and leaf expansion, smaller leaf area and favoured root over shoot growth. Similar behaviour was reported by Xia (1994) in the same crop. Lizana (2006) reported that water stress resulted in reductions of 72% pods $plant^{-1}$, 32% seed pod^{-1} and 83% decrease in grain yield of common bean.

The effect of water stress on yield also depended on duration of stress and the plant growth stage at which the stress occurred. El Nadi (1969) reported that faba bean was more sensitive to water stress at flowering than vegetative phase. Xia (1994) and Mwanamwenge *et al*. (1998) observed that water stress occurring in faba bean at early podding phase caused 50% reduction in seed yield. The seed number per plant and pods diminished by 38% when water stress occurred after flowering. They concluded that faba bean was more sensitive to water stress during podding than any other phenological stage. In cotton, water stress during the reproductive phase caused the highest yield decrease (Pettigrew 2004). However, in barley post-anthesis water stress caused the highest reductions in barley tillers, spikes, number of grains per plant, grain mass and the final grain yield (Samarah 2005).

2.5 Drought and Water Scarcity

Drought refers to the lack of rainfall or extended period of dryness or extremely low rainfall which results in devastating effects on crops, humans and animal lives. Drought may be classified as meteorological, agronomic, physiological or hydrological depending on the field use of water (Dracup and Piechota 1999, Wesley *et al*. 2002). Meteorological drought refers to the period with no adequate rainfall recorded statistically in an area per annum (Shao *et al*. 2009). Soil water declines and the atmospheric conditions continue to cause water deficit through transpiration or evaporation. Agronomic drought which refers to when there is insufficient soil water to meet crop water requirements (Rosenberg 1979). The lack of adequate rainfall leads to soil water deficit which results in poor crop production.

Drought severely affects dry land farming resulting in food price increases exacerbating the already poor nutritional levels of communities and overburdening of the social budget (Passioura 2007). Generally, South Africa is classified as a dry country due to lack of adequate rainfall in most parts of the country (Otieno and Ochieng 2004). In South Africa, 65% of the country receives less than 500 mm and an average national rainfall of 450 mm a year which is far below than the world average of 860 mm. (South Africa Yearbook 2010/11). South Africa receives 200 mm of rainfall in the west part which is 21% of the country land size. The pattern of rainfall occurrence is known as unpredictable and unreliable which poses uncertainty challenges in agriculture (Bennie and Hensley 2001). There is high frequency of prolonged drought which affects crop production through water stress and sometimes the dry spell terminates accompanied by severe floods which damage crops causing reduction in yields (South Africa Yearbook 2012/2013).

2.6 Crop Responses to Water Stress

Once plants are exposed to water stress, they begin to respond in defence for survival. The shortage of water at any stage of plant growth may cause molecular and morphological effects. Plant responses vary according to plant species, phase of development, degree and period of water stress (Lisar *et al*. 2012).

2.6.1. Plant growth responses

In response to drought, plants restrict the leaf size and number as a mechanism to cope with limited water availability through minimizing water loss through transpiration. If drought occurs when a crop has a large leaf area, the leaf desiccates and plucks off the leaf (leaf abscission) and finally the whole plant dies if water stress becomes terminal. The attainment of normal growth, flowering and ultimately reasonable yields under water stress conditions is considered useful in crops under rain-fed conditions (Beck *et al*. 2007). In crops such as sorghum there was a 14 to 16% reduction in canopy photosynthesis, the older leaves systematically senesce while the young ones retain turgidity, stomatal conductance and assimilation (Blum 2004). Such a drought response mechanism provides an opportunity for the increase in harvest index (Chaves *et al*. 2002).

In the event that drought is gradually occurring in a season plants can escape dehydration by cutting short their life cycle (Blum 2004). This mechanism is known as drought escape. Water stress has been reported to cause early flowering, shorter flowering duration and ultimately early maturity. Similar effect was observed in potato by Heuer and Nadlet (1995) and also reported on soya bean by (Specht *et al*. 2001). When bean plants were grown under adequate water they favoured vegetative growth instead of yield formation, while plants grown under water stress flowered earlier. The tendency to favour vegetative growth had negative implications on harvest yield where dry matter accumulation was observed in the vegetative parts compared to yield components (De Costa *et al*. 1996). Drought escape mechanism was adopted by breeders were they bred for short season varieties which flower early and produce an economic yield in the peak of a doubtful rainfall season before rain peters off (Araus *et al*. 2002). The short season crop practice has been widely adopted in dry arid regions with substantial results (Kumar and Abbo 2001).

2.7 Mitigating Water Stress: Planting Date Selection

According to Blum (1982) the effects of drought can be mitigated by various management practices including crop diversification and proper selection of planting date. In drought prone area, maximum grain yields are attained when maize is planted early season thus avoiding the flowering and grain filling phases coinciding with mid-season drought (Khokhar *et al*. 2010). In environments with dry summers the effects of extreme drought events were masked by early planting; early planting allows roots to develop to depth before soil water reserves become limiting (Kgasago 2006, Hu and Wiatrak 2012, Tsimba *et al*. 2013). However this is affected by climate change and changes in seasonal patterns of rainfall (Pathak *et al*. 2012) hence there is need for a recent study in Makhathini assessing the possibility of mitigating drought through planting date selection.

2.8 Conclusion

Sweet potato, maize and dry beans are important crops in Africa. They contribute to food and nutritional security, especially amongst subsistence farmers in semi and arid parts of the continent. The challenge still remains of low crop yield and sometimes crop failure due to poor choice of planting date. Traditionally known planting dates have been affected by shifting rainfall patterns, changes in rainfall distribution and temperatures. Crop yield is influenced by water availability of which the review has shown drought is a major threat in South Africa. There is a need to evaluate the performance of the three crops under different planting dates in order to minimize the effects of temperature and drought associated with planting dates. It would generate information useful in advising farmers on optimal planting dates for the different crops in order to maximize yield.

CHAPTER 3

Materials and methods

3.1 Plant Material

3.1.1 Maize

Seed of maize variety SC701 (Seed Co, Zimbabwe) was sourced from Pongola. SC701 is a medium to late maturing variety which may be grown for green maize or grain depending on the farmer's target market. The grain is white in colour with a yield potential of 3 - 7 tonnes per hectare. SC701 takes 150 days to physiological maturity temperate areas. The maize variety also takes 78 days to 50%. SC701 has high prolific and disease resistance especially to common rust and diplodia.

3.1.2 Dry beans

Speckled dry beans locally named Ukulinga was purchased from Pietermaritzburg. The cultivar was jointly bred by McDonald seeds and Pro-Seed Company. Ukulinga is a late maturing (120 days) upright bushy variety of high yielding and remarkable disease resistance character and has large seed size of 52 g per 100 seed. The variety is also resistant to lodging, shattering, mosaic virus and fungal diseases such as rust and angular leaf spot. When mature, the large pods show red markings in appearance. The Ukulinga bean is a dry field bean which is a medium to long season cultivar.

3.1.3 Sweet potatoes

Sweet potato A40 cultivar (University of KwaZulu Natal, South Africa) was propagated by cuttings sourced from Makhathini Agricultural Research station. The sweet potato has white skin with white flesh and is a medium to long season variety which reaches maturity at about 120 days. It has a yield potential of 35 tonnes ha^{-1}. It is also resistant to Alternaria blight.

3.2 Description of Experimental Site

Field trials were conducted at Makhathini Research Station (27°24ʹ S; 32°11ʹE; 69 m a.s.l) in the irrigation scheme of Umkhanyakude district of KwaZulu–Natal province during the summer season of 2013/2014. The average rainfall of the area is 500 mm per annum with average temperatures of 34°C and extremes of around 48°C in summer. The area is flat land with fluvisols located in alluvium deposits and naturally fertile soils with minimal drainage and runoff. The soils are 22% clay content with a pH value of 5.52 and 1% acid saturation. The soils have deficiencies of nitrogen and phosphorus for bean, maize and sweet potato production. Weather parameters were monitored by an automatic weather station (AWS) (ARC – Institute for Soil, Climate and Water) situated within the research station.

3.3 Experimental Design

The experimental design was split-plot design arranged in a randomised complete block design (RCBD) with three replications. Main plots were allocated to the planting dates and there were three crops treated separately. The experiments included three crops: maize, sweet potato and dry beans. The experiment was conducted under rain-fed conditions. There were four planting dates as follows: first – 20^{th} of November 2013, second – 18^{th} of December 2013, third – 16 of January 2014 and fourth – 19^{th} of February 2014. The selection of the four planting dates was based on the existing cropping practice by the subsistence farmers at Makhathini area. For each planting date, the main plot size was 18 m x 18 m (324 m^2) and individual plots, for all crops, were 5 m x 5 m (25 m^2). Spacing between plots was 1.5 m. Plant populations used for each crop were based on recommended populations under rain-fed farming maize 22 500 plants ha^{-1}, beans 115 000 plants ha^{-1} and sweet potato 30 000 plants ha^{-1}. Therefore; for maize plant spacing was 0.75 m between rows and 0.5 m within rows translating to 77 plants per plot, 45 plants being experimental units. For sweet potatoes, plant spacing was 0.90 m between rows and 0.3 m within rows translating to 102 plants per plot, 60 plants being experimental units. For dry beans, plant spacing was 0.75 m between rows and 0.15 m within rows translating to 238 plants per plot, 170 plants being experimental units.

3.4 Land Preparation and Crop Management

Land preparation for all three crops involved disking and rotovating the fields to achieve a fine seedbed. Prior to planting, soil samples were taken and submitted for soil textural and fertility analyses at KZN Department of Agriculture and Environmental Affairs; Soil Analytical Services, Pietermaritzburg. Results of soil fertility analysis revealed that there was need for fertiliser application to meet all the crops' requirements for macro and micro-nutrients (Table 3.1). Weeding for all the crops was routinely done by hand-hoeing.

Table 3.1: Results of soil fertility analyses for Makhathini Research Station.

pH	P	K	Ca	Mg	Zn	Mn	Cu
(KCl)	(mg L^{-1})						
5.52	30	527	952	321	2.4	17	4.5

Pre- emergence herbicide, Metolachlor 915 E.C was applied to the maize and dry beans field at the rate of 0.55 and 1.5 L in 30 L of water ha^{-1}; this was according to the manufacturers' (Villa Crop Protection (Pty) Ltd, South Africa) recommended rates for the crops under rain-fed farming. For maize and dry beans two seeds were planted per planting station and thinned 14 days after emergence. A40 Sweet potato variety cuttings of 40 cm in length were planted three nodes deep on ridges. Rat poison was applied around all the plots at planting. Basal fertilizer mono ammonium phosphate (M.A.P) was applied in all the plots at planting at a rate of 90 kg ha^{-1}. Polythene nets were erected around each bean plot to prevent rabbit entry. Top dressing fertilizer lime ammonium nitrate (L.A.N) was applied on all three crops three weeks after emergence by hand using the banding method at a rate of 145 kg ha^{-1} (maize), 105 kg ha^{-1} (dry beans) and 320 kg ha^{-1} (sweet potatoes). At the same time stalk borer granules containing pyrethroid (Kombat Pty Ltd, South Africa) was applied in maize.

3.5 Data Collection

3.5.1 Maize

Data collected during the trials included seedling emergence, weekly plant height and leaf number after establishment and fortnight biomass accumulation. Timing of key phenological events (days to seedling establishment, tasselling, silking and maturity) were monitored weekly. Emergence was defined as protrusion (20 mm) of the coleoptile through the soil. Plant height (cm) was measured from the base of the plant to where the tassel branching begins. A leaf was counted when it was fully expanded with visible leaf collar. Biomass accumulation (g) was measured using a digital scale GM-500 (Lutron Electronic, USA) on a plant destructively sampled (8 plants per plot) from the border rows. Time to establishment was defined as the number of days from planting taken for 90% of the plants in a plot to emerge. Time to tasseling was defined as number of days taken from planting to when 50% of the plants in a plot had emerged tassels. Time to silking was defined as the number of days from planting to when 50% of the plants in a plot had emerged silks. Maturity was defined on the basis of harvest maturity (when plants seemed to be sufficiently dry) not physiological maturity. Data collected at harvest were; total biomass, grain biomass (economic yield), ear size characteristics, kernel rows per ear and kernel number per row. Thereafter, harvest index was obtained by dividing economic yield with total above ground biomass.

3.5.2 Sweet potatoes

Sweet potato plants were allowed two weeks for establishment (growth of fibrous roots) before data collection commenced. Data collected during the trial were weekly, leaf number and vine length (cm). Timing of key phenological events (days to flowering and maturity) was monitored weekly during the trial. Vine length was measured from the base of the plant to the apex of the longest vine. A leaf was counted after it was fully expanded. Time to flowering was defined as when 50% of the plants in the plot had at least one open flower. Maturity was defined as when total leaf area stayed constant and then began to decline. At harvest data collected were; whole plant biomass (g), above ground biomass (g) as well below ground biomass (g) (marketable yield). Thereafter, harvest index was determined as the ratio between marketable yield and whole plant biomass.

3.5.3 Dry beans

Emergence will be defined as protrusion of the coleoptile through the soil. This was carried out daily, until 90% emergence or until there was no new emergence. Data collected during the trial were plant height (cm), leaf number and biomass accumulation. Timing of key phenological events (days to flowering, podding and maturity) was monitored weekly. Plant height was measured from the ground to the highest point of the crop. A leaf was counted when the trifoliate was fully developed and expanded. At harvest yield data collected included total biomass (g) and grain yield (g). Thereafter, harvest index was determined as the ratio between grain yield and whole plant biomass.

3.6 Statistical Analyses

Data collected were subjected to analysis of variance (ANOVA) using GenStat® Version 16 (VSN International Ltd, UK) at the 5% level of significance (see Appendix section). Means of significantly different variables were separated using the least significant difference (LSD) test.

Chapter 4

Results

4.1. Weather Parameters

Observed weather data for the duration of the trials showed that temperatures were relatively high. During the first planting date, minimum temperatures were ≈15°C while maximum temperatures ranged between 25°C and 40°C. During the first 40 days after planting, between 5 mm and 20 mm of rainfall were received over a period of five days. Thereafter, there was a dry period between 40 and 60 days after planting and also between 80 and 95 days after planting. At the end of the first growing season (between 100 and 105 days after planting) 50 mm of rainfall had been received.

The second planting date season received less than 50 mm of rainfall during the first two months. There was a hailstorm 82 days after planting during which 110 mm of rainfall were received. A heavy downpour also occurred 52 days after planting during the third growing season. The third planting date experienced an extremely dry period (< 5 mm) 68 days after planting up to the end of the growing season. During the fourth planting date, a flash flood (110 mm in a day) was experienced 17 days after planting. Thereafter, from 32 days after planting up to the end of the trial, only 5 mm cumulative rainfall was recorded. Minimum temperatures during this period also dropped from ≈15°C to ≈10°C (Figure 4.1).

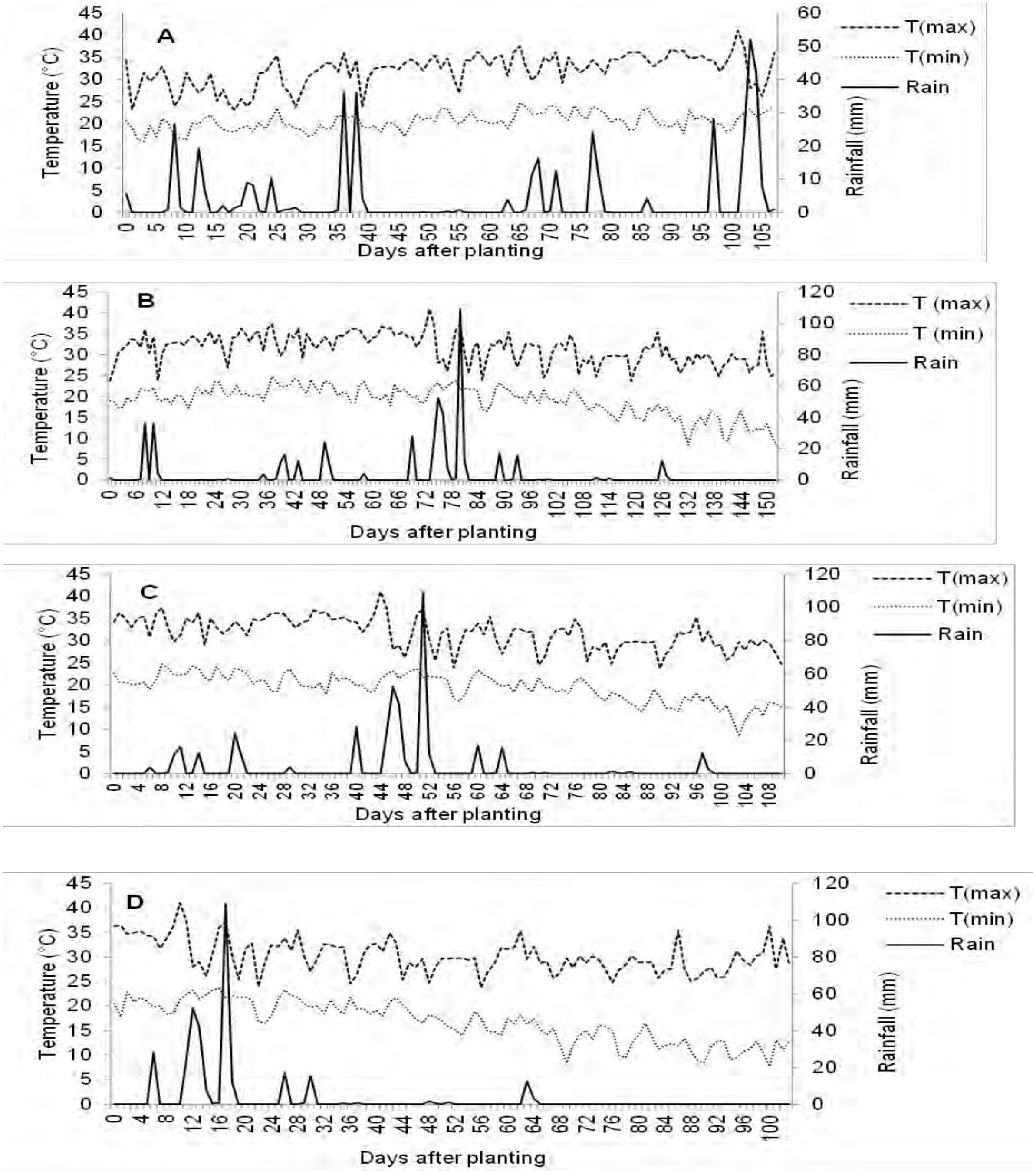

Figure 4.1: Changes in daily weather parameters (Tmax, Tmin and rain) observed during the four planting dates: A – Planting date 1; B – Planting date 2; C – Planting date 3; and D – Planting date 4 at Makhathini Research Station.

4.2 Growth, development and yield of maize as affected by planting date

4.2.1 Emergence and Growth

Significant differences (P<0.05) were observed between planting dates with respect to emergence. The interaction between planting dates and time was highly significantly different (P<0.001) (Fig 4.2). The highest emergence (98%) was observed in the third planting date while the lowest seedling emergence (86%) was observed in the second planting date.

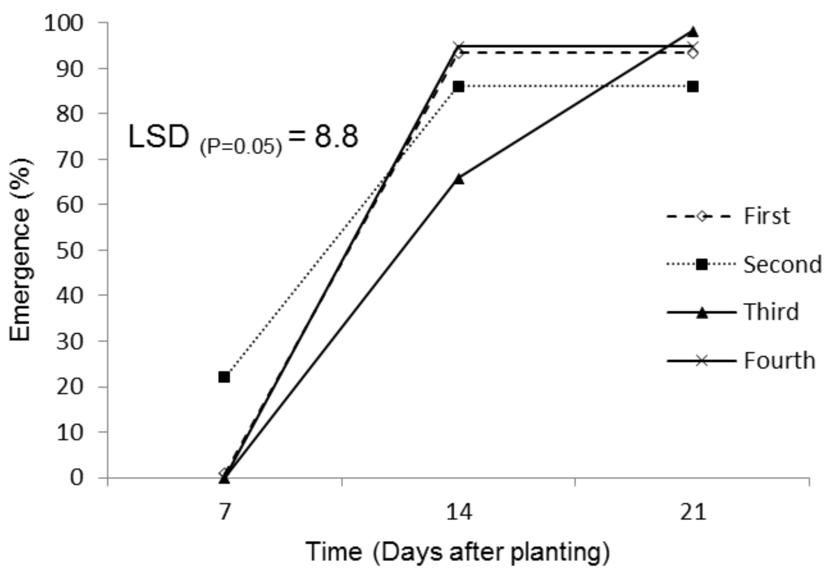

Figure 4.2: Weekly emergence of maize seeds planted on four different planting dates (first – 20th of November 2013; second – 18th of December 2013; third – 16 of January 2014; and fourth – 19th of February 2014).

Plant height showed highly significant differences (P<0.001) between planting dates, time (DAP) and the interaction between the two (Fig 4.3). The average tallest plants (81.5 cm) were observed in the first planting date while the average shortest plants (56.9 cm) were observed in the second planting date. Results of leaf number showed significant differences (P<0.05) among planting dates, time (DAP) and the interaction between the two (Fig 4.4). Maize planted on the first planting date had the highest number of leaves (8.84) while maize planted on the last planting date had the least number of leaves (5.98). For all planting dates, the trend was such that leaf number increased up to ≈70 DAP; thereafter, there was consistent decline.

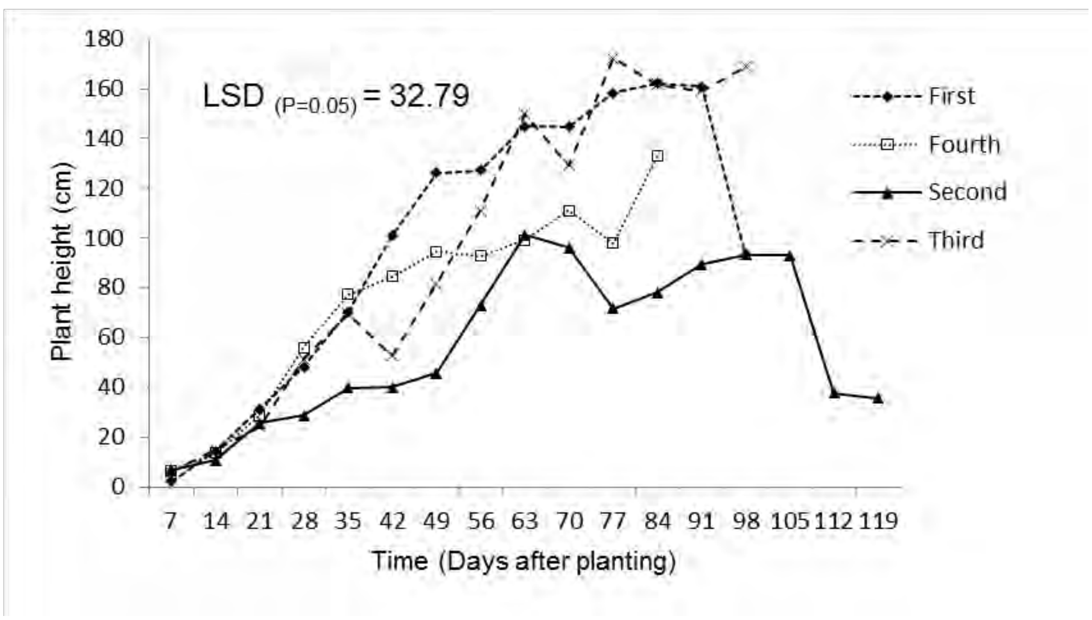

Figure 4.3: Weekly plant height of maize planted on four different planting dates (first – 20th of November 2013; second – 18th of December 2013; third – 16 of January 2014; and fourth – 19th of February 2014).

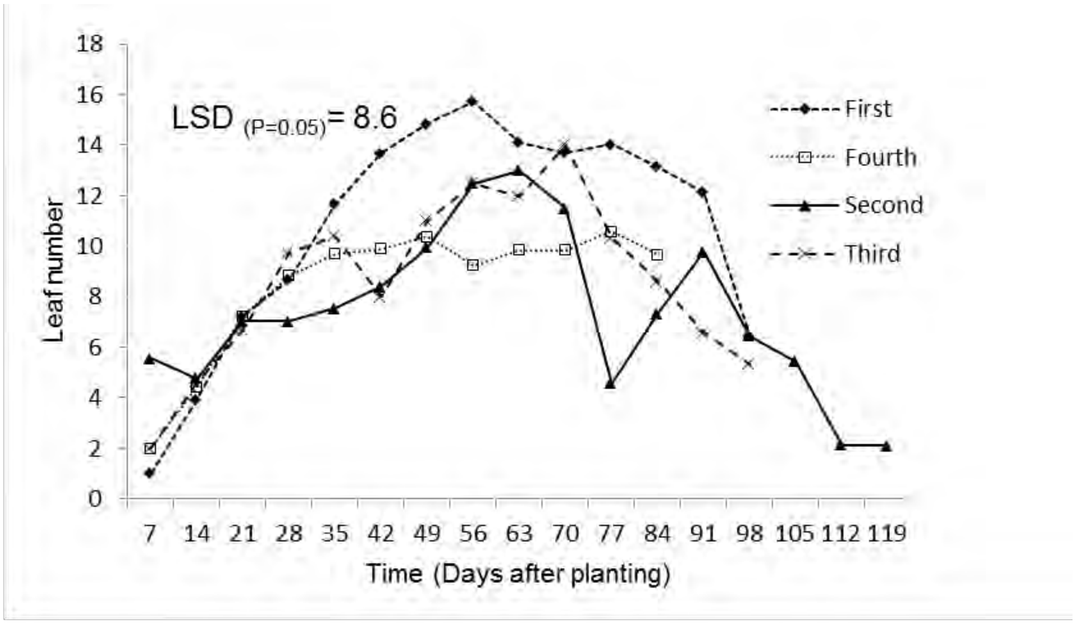

Figure 4.4: Weekly leaf number of maize planted on four different planting dates (first – 20th of November 2013, second – 18th of December 2013, third – 16 of January 2014 and fourth – 19th of February 2014).

Results of fresh and dry mass showed a similar trend where highly significant differences (P<0.001) were observed among planting dates, time and the interaction between planting date and time (DAP) (Fig 4.5 & Fig 4.6). Dry mass accumulation was greater in the first planting date (199 g) followed by the third planting date (133.8 g) and lastly the second planting date (22 g) (Fig 4.6).

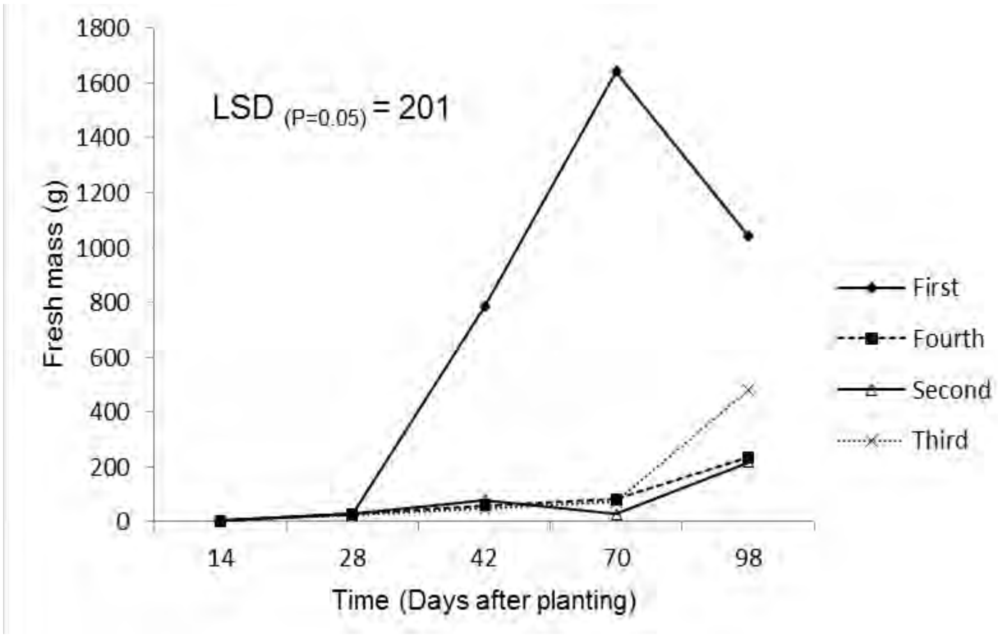

Figure 4.5: Fortnight whole plant fresh mass (g) plant^{-1} of maize planted on four different planting dates (first – 20th of November 2013; second – 18th of December 2013; third – 16 of January 2014; and fourth – 19th of February 2014).

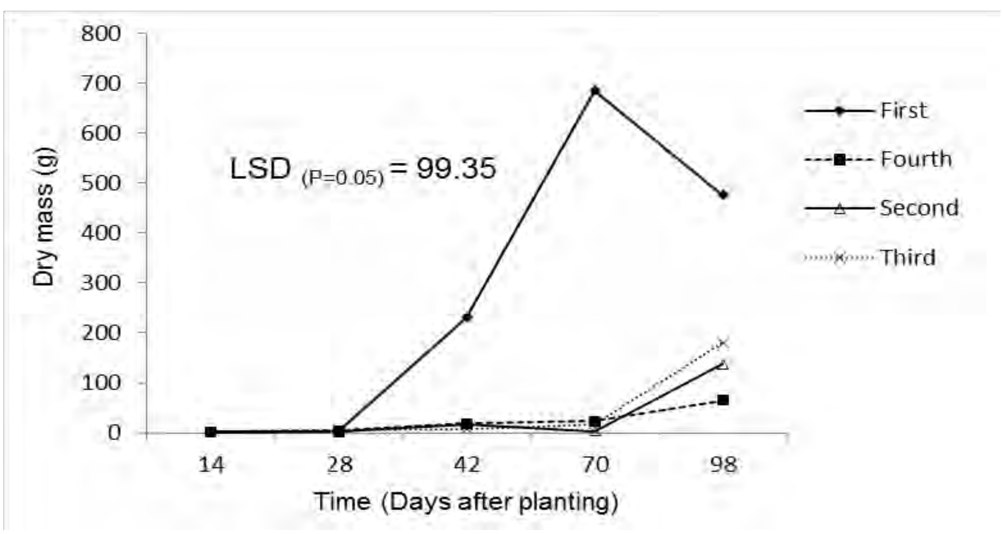

Figure 4.6: Fortnight whole plant dry mass (g) plant^{-1} of maize planted on four different planting dates (first – 20th of November 2013; second – 18th of December 2013; third – 16 of January 2014; and fourth – 19th of February 2014).

4.2.2 Phenology

No significant differences were observed ($P>0.05$) in time to establishment and time to tasseling for the four planting dates. Although not statistically different, emergence was shown to occur earlier in the third and fourth planting dates compared to the first and second last planting dates, respectively (Table 4.1). This trend was also similar with respect to tasseling; plants tasselled earlier in the third and fourth planting dates compared with the first and second planting dates, respectively (Table 4.1). Time to silking and time to maturity varied significantly ($P<0.001$) among planting dates. For the second planting date, plants did not reach the silking stage because they succumbed to water stress soon after tasseling hence no results are reported for times to silking and maturity (Table 4.1). Interestingly, despite plants showing faster development in the third and fourth planting dates, results showed that they matured later than plants during the first planting date (Table 4.1).

Table 4.1: Phenology of maize when planted on four different planting dates (first – 20th of November 2013, second – 18th of December 2013, third – 16 of January 2014 and fourth – 19th of February 2014).

Planting date	**Time to establishment**	**Time to tasseling**	**Time to silking**	**Time to maturity**
	(days)			
First	6a	60a	67a	100a
Second	7.67a	65.3b	–	–
Third	5.67a	56a	63a	130b
Fourth	5.67a	58a	65a	108a
$LSD_{(P=0.05)}$	1.91	7.73	5.31	9.99
F Pr.	0.117	0.106	<0.001	<0.001

4.2.3 Harvest Parameters

Results of fresh mass, dry mass, fresh cob mass, dry cob mass and dry stalk mass differed significantly ($P<0.05$) among planting dates (Table 4.2). Fresh and dry mass accumulation was more than 100% in the first planting date compared to the other planting dates. Whole plant fresh and dry mass were the only parameters measured for the second planting date; there was no economic yield. Fresh cob mass was 281 g per plant in the first planting date, 150 g in the fourth planting date and 150 g in the third planting date, respectively (Table 4.2). Dry cob mass did not follow the same pattern; the trend was such that first planting > third planting > fourth planting. Cob length also had a different pattern; longer cobs were observed in the third planting (15.93 cm) followed by the first planting (15.40 cm) then lastly the fourth planting (12.33 cm). Results of 100 grain mass and number of kernel rows per ear showed highly significant differences ($P<0.001$) among planting dates. The 100 grain mass was such that the first planting date (36.67 g) > the third planting date (34 g) > the fourth planting date (27.89 g). Number of kernels per row showed no significant differences between the planting dates. Lastly, harvest index differed significantly ($P<0.05$) among planting dates. Results showed that harvest index was higher for the third planting date (40.9%), followed by the first planting date (33.6%) and lastly the fourth planting date (19.4%).

Table 4.2: Yield and yield parameters of maize when planted on four different planting dates (first – 20th of November 2013; second – 18th of December 2013; third – 16 of January 2014 and fourth – 19th of February 2014).

Planting date	Fresh mass	Dry mass	Fresh Cob mass	Dry cob mass	100 grain mass	Dry stalk mass	Cob length (cm)	No of rows per ear	No of kernels per row	Harvest Index (%)
	———	———	———	g	———	———				
First	1041a	476a	281a	145a	36.67a	333a	15.40a	12.67a	20a	33.6a
Second	218b	137b	–	–	–	–	–	–	–	–
Third	437b	287b	150b	118a	34a	193a	15.93a	10.80a	18.8a	40.9a
Fourth	419b	156b	176a	58b	27.89b	135b	12.33a	12.09a	15.2a	19.4b
Mean	529	264	152	80	24.64	165	10.92	8.89	13.5	23.5
LSD	336.4	161.5	123.8	86.0	4.78	187.8	4.78	2.272	15.01	20.13
F pr. **(P=0.05)**	0.005	0.007	0.011	0.027	<0.001	0.030	0.061	0.059	0.058	0.029

4.3 Growth, development and yield of sweet potato as affected by planting date

4.3.1 Growth and phenology

Results of sweet potato weekly leaf number showed significant differences ($P<0.05$) among planting dates, time (DAP) and the interaction between the two (Fig 4.7). The first planting date trial failed 35 days after planting while the third and fourth planting date trials failed immediately after planting. Only the second planting date trial survived; therefore results reported here are for the second planting date only. Leaf number increased with time reaching up to 280 leaves at the end of the experiment. During the second planting, plant height increased over time mimicking the sigmoid growth curve. During the second planting season, the time taken to flowering was 102 days after planting while the time taken to maturity was 154 days after planting.

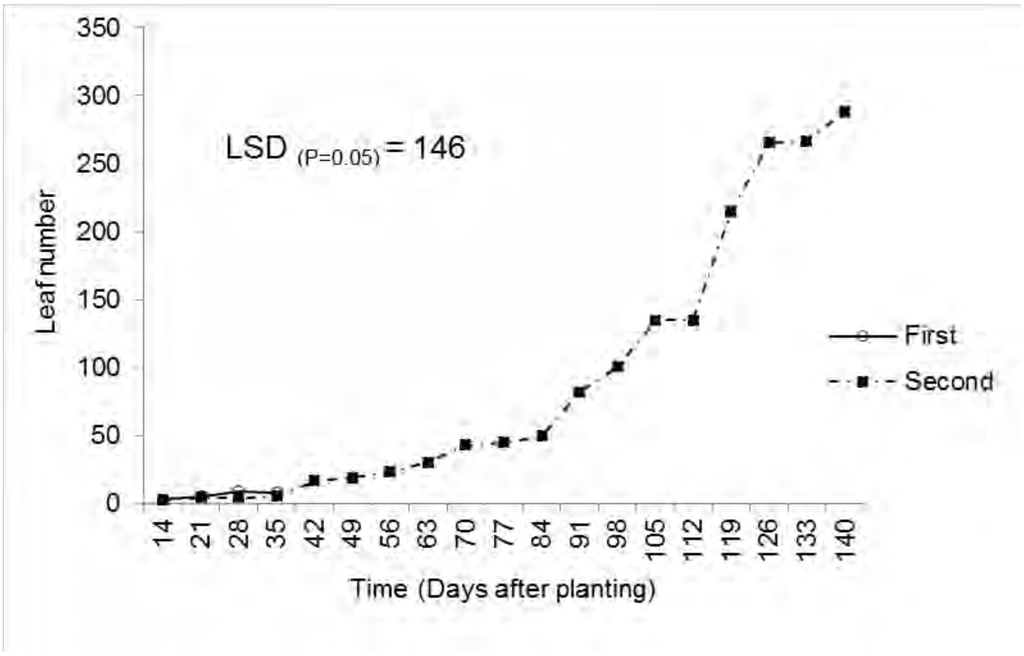

Figure 4.7: Weekly leaf number of sweet potato plants planted on two different planting dates (first – 20th of November 2013 and second – 18th of December 2013).

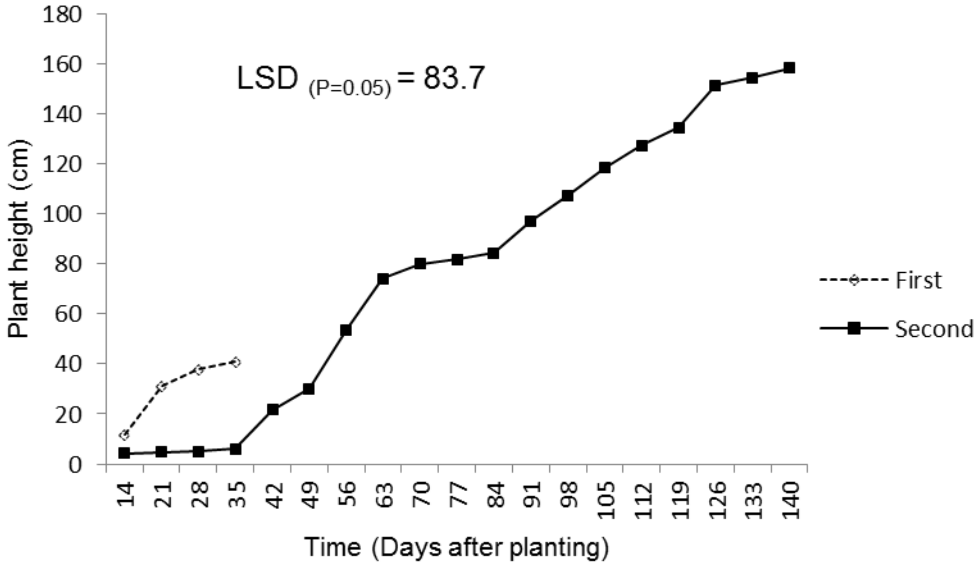

Figure 4.8: Weekly plant height of sweet potato plants planted on two different planting dates (first – 20th of November 2013 and second – 18th of December 2013)

4.3.2 Harvest parameters

Table 4.3: Yield and yield parameters of sweet potato plants planted on the second planting date (second – 18th of December 2013).

Fresh mass plant $^{-1}$	**Dry mass plant $^{-1}$**	**Fresh storage root mass plant $^{-1}$**	**Dry storage root mass plant $^{-1}$**	**No. of storage roots plant $^{-1}$**	**Harvest Index**
------------------	------------------	**g**	------------------		**%**
13 467	3 365	2 172	794	29	24

Figure 4.9: Yield sweet potato plants planted on the second planting date (second – 18th of December 2013).

4.4 Growth, development and yield of Dry beans as affected by planting date

4.4.1 Emergence and growth

Highly significant differences (P<0.001) were observed among planting dates, time (DAP) and the interaction between the two (Fig 4.10). The highest seedling emergence (88.56%) was observed in the third planting date while the lowest (11.73%) was observed in the second planting date. Based on means of days after planting seedling emergence was approximately 3% at 7 DAP, 47.17% at 14 DAP and 62.05% at 21 DAP. Dry beans maximum emergence occurred between 7 and 14 DAP in the first, second and fourth planting dates while it occurred 14 and 21 DAP in the third planting date.

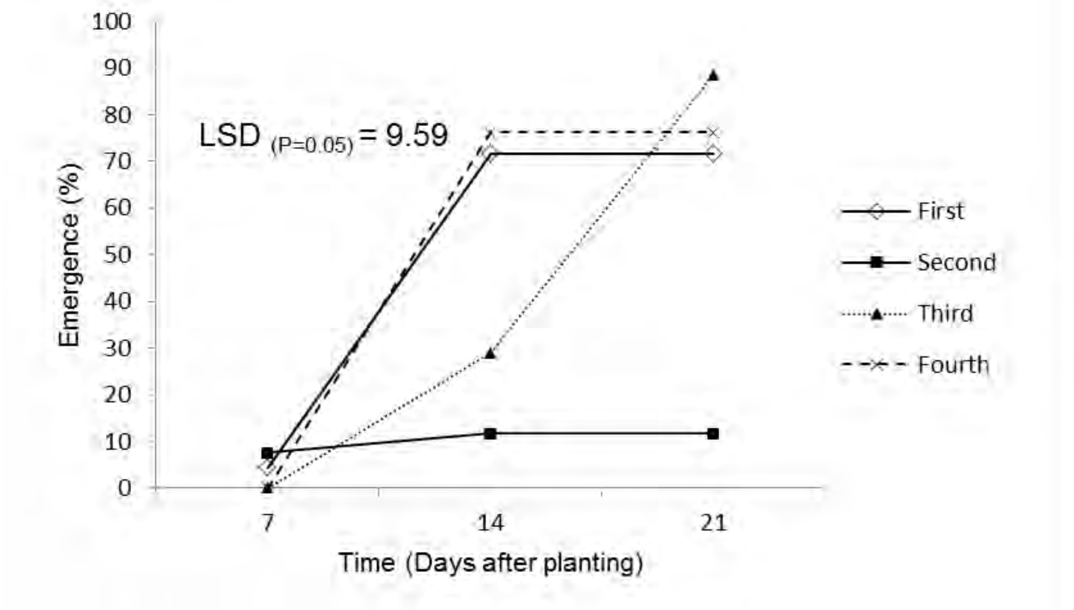

Figure 4.10: Weekly emergence of dry beans seeds planted on four different planting dates (first – 20th of November 2013; second – 18th of December 2013; third – 16 of January 2014; and fourth – 19th of February 2014).

Results of weekly plant height and leaf number also showed highly significant differences ($P<0.001$) among planting dates, time (DAP) and the interaction between the two (Figure 4.11 & 4.12). The tallest plants (25.68 cm) and the most number of leaves (33.07 cm) were observed during the first planting date (Figure 4.11 & 4.12). The shortest plants (18.9 cm) and the least number of leaves (24.75) were observed in the third planting date trial. The second planting date trial failed 42 DAP. In both growth parameters (plant height and leaf number) there was an increase up to approximately 56 DAP then a decline (Figure 4.11 & 4.12).

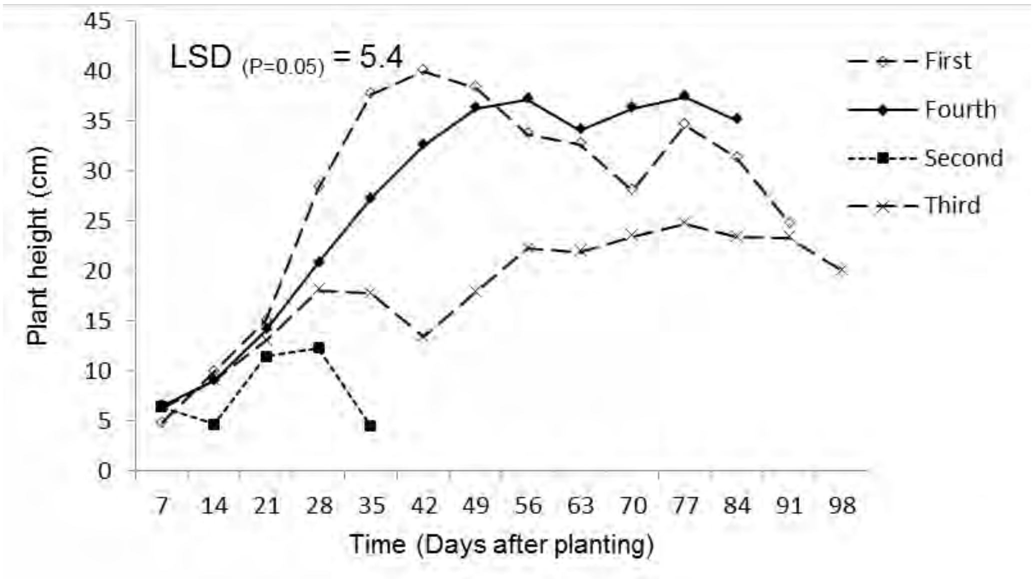

Figure 4.11: Weekly plant height of dry beans planted on four different planting dates (first – 20th of November 2013, second – 18th of December 2013, third – 16 of January 2014 and fourth – 19th of February 2014).

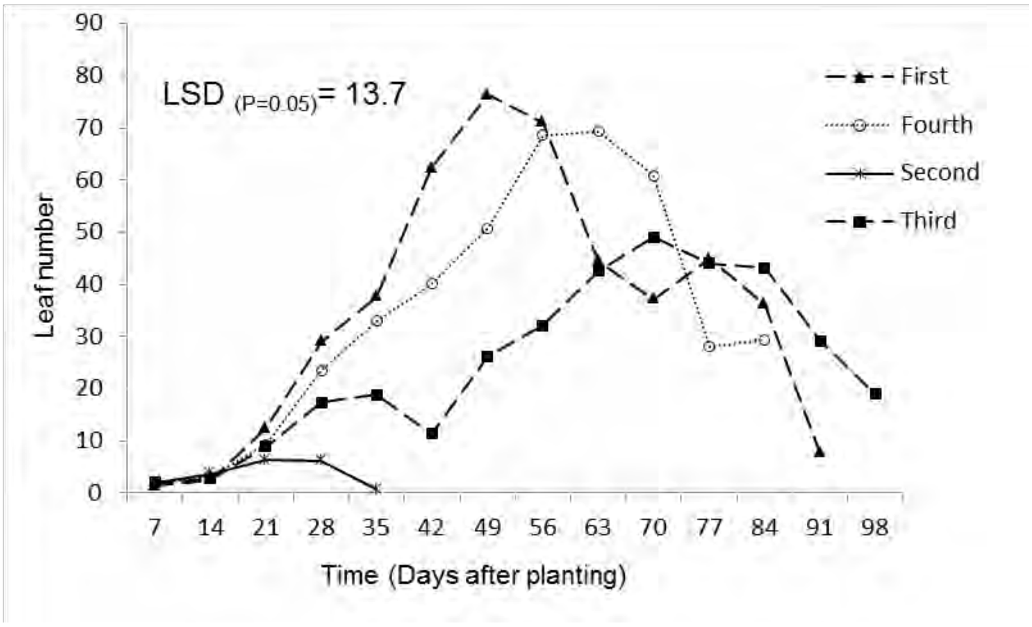

Figure 4.12: Weekly leaf number of dry beans planted on four different planting dates (first – 20th of November 2013; second – 18th of December 2013; third – 16 of January 2014; and fourth – 19th of February 2014).

Results of fortnightly fresh and dry mass differed significantly ($P<0.05$) among planting dates, time and the interaction between planting dates and time (Fig 4.13 & Fig 4.14). Means of planting dates did not follow the same trend as plant growth parameters. The highest fresh (FM) (32 g) and dry mass (DM) (10.21 g) were observed during the fourth planting date followed by the first planting date (FM = 22.6 g; DM = 4.63 g) and then lastly the third planting date (FM = 12.8 g; DM = 3.61 g).

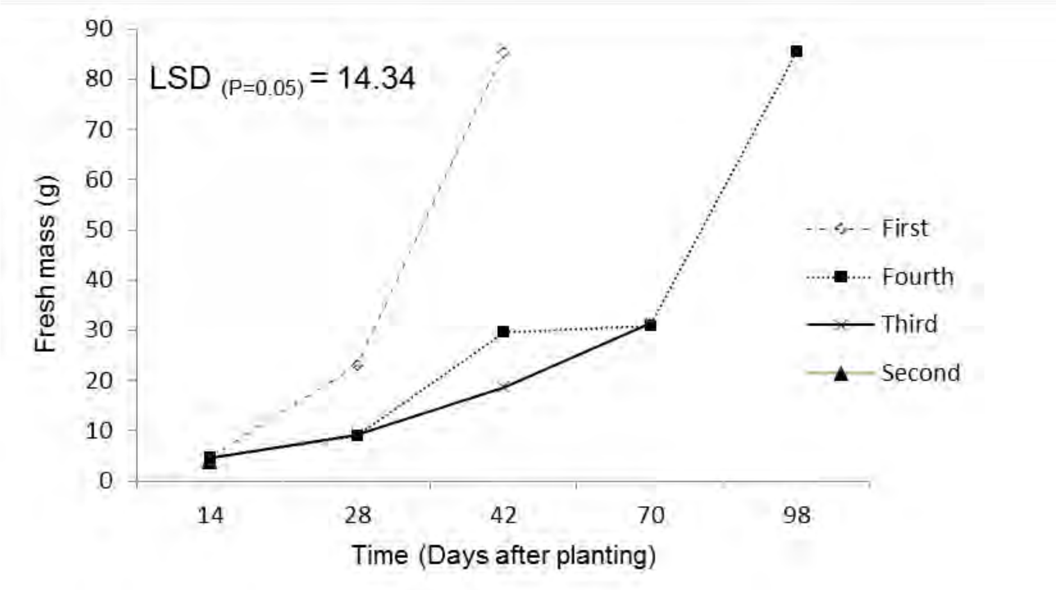

Figure 4.13: Fortnightly whole plant fresh mass of dry beans planted on four different planting dates (first – 20th of November 2013; second – 18th of December 2013; third – 16 of January 2014; and fourth – 19th of February 2014).

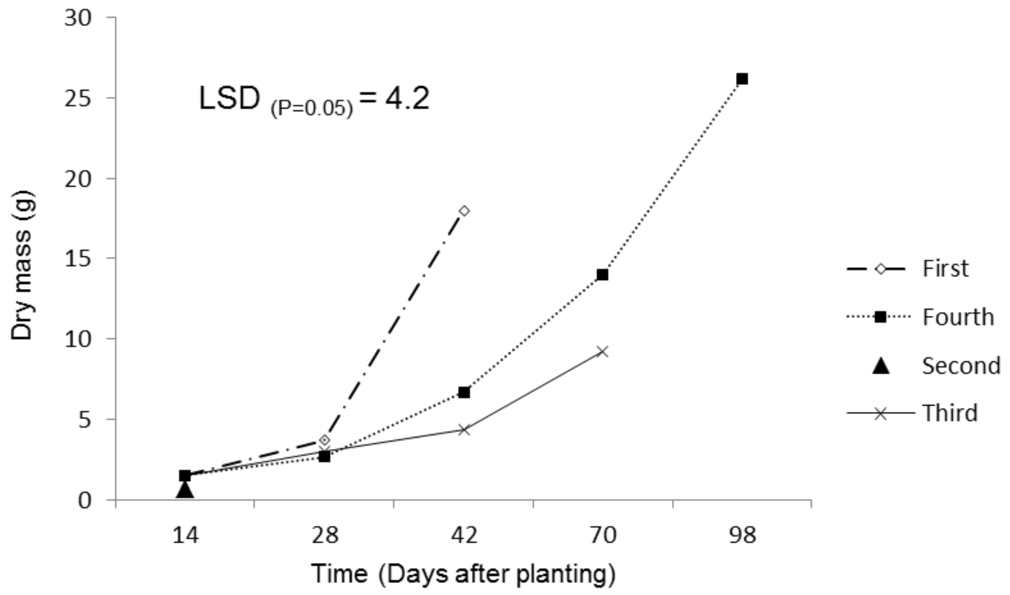

Figure 4.14: Fortnightly whole plant dry mass of dry beans planted on four different planting dates (first – 20th of November 2013; second – 18th of December 2013; third – 16 of January 2014; and fourth – 19th of February 2014).

4.4.2 Phenology

The average number of days taken by dry beans to emerge was 10.5 days (Table 4.4). Flowering occurred earlier (42 days after planting) for the fourth planting date while the first planting date took the longest to flower (63 days after planting) (Table 4.4). The second planting date trial failed before it reached the flowering stage. Results of time to podding and time to maturity showed significant differences ($P<0.05$) among planting dates (Table 4.4). The fourth planting date trial also podded earlier (63 DAP) compared to the first (75 DAP) and third planting dates (79 DAP), respectively. The first and second planting date trials did not make it to maturity and as expected the fourth planting date trial matured earlier (84 DAP) than the third planting date trial (95 DAP).

Table 4.4: Phenology of dry beans planted on four different planting dates (first – 20th of November 2013; second – 18th of December 2013; third – 16 of January 2014; and fourth – 19th of February 2014).

Planting date	Time to establishment	Time to flowering	Time to podding	Time to maturity
	(Days)			
First	7	63	25.7a	–
Second	14	–	–	–
Third	14	56	79.3b	95.67b
Fourth	7	42	63.0a	84a
Mean	10.5	40.25	42.0	44.92
LSD	-	-	45.26	4.03
F pr (P=0.05)	-	-	0.019	< 0.001

4.4.3 Yield and yield parameters

No significant differences (P> 0.05) were observed for number of pods per plant, seeds per pod and harvest index for the third and fourth planting dates. Significant differences (P<0.05) were observed for seed mass for the third and fourth planting dates (Table 4.5).

Table 4.5: Yield and yield parameters of dry beans plants planted on the third and fourth planting dates (third – 16 of January 2014 and fourth – 19th of February 2014).

Planting date	No of pods plant $^{-1}$	No of seeds per pod	Seed mass (g)	Harvest Index (%)
Third	6.33	6.17	28	35.3a
Fourth	11.22	3.15	33	13.5a
Mean	8.78	4.66	30.67	24.4
LSD	–	–	–	29.66
F pr. (P=0.05)	0.098	0.105	0.015	0.088

4.5 Discussion

The objective of the study was to evaluate the feasibility of using planting date as a management tool for managing water stress under rain-fed agriculture. Secondary to this was to establish optimal planting dates associated with maximum growth and productivity (yield) for the selected crops (maize, sweet potato and dry beans). Observed weather characteristics during the study showed a pattern of uneven rainfall distribution characterised by flash floods and mid-season dry spells which were often accompanied by high temperatures (Figure 4.1). The variations in weather parameters, chiefly rainfall, created distinct scenarios, with drought and heat stress occurring at different stages of crop growth depending on planting date. This variability and associated exposure of crops to stresses emphasised that indeed planting date selection could be used to ensure that crops avoided stress during critical growth stages. This observation concurred with reports by Mabhaudhi (2009) working on maize, Mbatha (2010) working on wild mustard, Zulu (2010) working on wild water melon, and Sinefu (2011) working on bambara groundnut.

With respect to maize seed emergence, the differences observed between planting dates can be attributed to rainfall and temperature variations during the season. The lowest seedling emergence and establishment in second planting date (86%) was caused by a combination of extremely high temperatures (>35°C) and lack of water. According to Peacock *et al*. (1990), extremely high temperatures (>35°C) hinder maize seed emergence. In addition, a dry seedbed has been known to be hostile to emergence (Johnson and Asay 1993, Whalley *et al*. 1998). For dry beans, maximum emergence occurred between 7 and 14 DAP in the first, second and fourth planting dates because 35 mm amount of rainfall was received and it was enough to influence seedling emergence. During the third planting date, no rain was received in the first week and rain was only received between 7 and 14 DAP hence emergence was delayed.

Even after establishment, water stress limits crop growth (Anjum *et al*. 2003). During the second planting date, dry beans seedling mortality was high due to prolonged drought. Johnson and Asay (1993) also reported low seedling survival rates due to a dry seedbed under drought conditions. Previous studies on several crops such as cotton, maize and common bean have shown that water stress reduces yields (Pettigrew 2004, Monneveuv *et al*. 2006, Webber *et al*. 2006). Timing, duration and degree of stress plays an important role in severity of yield loss. In the current study, water stress that coincided with flowering and yield formation (grain and roots) resulted in low yields. Sweet potato only survived to maturity during the second planting date; the, first planting date failed 35 days after planting while the third and fourth planting dates failed to fully establish. This was as a result of extreme weather events (water stress and heat) during the establishment and early vegetative phase. Jaleel *et al*. (2008) reported that yam plants, a root crop similar to sweet potatoes were most sensitive to water stress during establishment and early vegetative stages. During the second planting date there was vegetative and root growth but without marketable storage root yield. This was caused by prolonged dry spells which followed after the crop establishment. The crop developed a ramified root system, possibly as an effort to enhance soil water capture. The growth of roots, at the expense of shoot growth, is a widespread plant response to declining soil water availability (Blum 1996, 2005).

In maize, temperature ranges of 25°C to 40°C favour vigorous vegetative growth. This concurs with Awal and Ikeda's (2001) findings in groundnuts. However, this trend was only true when high temperatures were not coupled with water stress. During the fourth planting date, the maize plants shed off some leaves when there was a prolonged dry period. According to Farooq *et al*. (2008), enhanced leaf senescence is a plant dehydration avoidance mechanism in order to mitigate water loss through transpiration. Gross and Kigel (1994) and Konsens *et al*. (1991) observed that dry beans exposed to high temperatures during flowering reduced pod and seed set. This was possibly due to flower abortion or failure of fertilisation at high temperatures. The occurrence of high temperatures during the third planting would thus account for the reduced pod number observed in dry beans.

Water stress and heat were not the only climate characteristics affecting crop growth and yield of all the crops. The flash floods which were experienced led to a significant loss of yield and in some cases crop mortality. Floods cause water saturation in the soil restricting oxygen availability to plant roots for growth (Whitmore and Whalley 2009). Water logging is a challenge during crop growth and like water stress, crop sensitivity to water logging is also dependant on timing, duration and severity. Maize is most sensitive to water logging during establishment (Dickin and Wright 2008). Based on observed weather data (Figure 4.1), all the planting dates were affected by floods; however, the effect of the floods on crop growth and yield varied depending on timing and crop sensitivity to aeration stress. The crops showed stagnant and retarded growth, particularly in maize and dry beans. Stalk lodging was also observed during and after floods showing that crop stand was greatly compromised; this also created a conducive environment for termites to attack the crop. Floods also contributed to the decline in leaf number as crops never recovered, especially young crops in second planting dates.

Based on the four planting dates, maize performed better in the first and third planting dates. Sweet potato was successful only in the second planting date though there were no marketable storage roots. Sweet potato showed high sensitivity to water stress and high temperatures particularly during early establishment and vegetative phases. Dry beans performed better during the fourth planting date. This shows that planting date selection could be explored to mitigate the effects of water stress occurring at critical growth stages under rainfed farming. It also provides an option for subsistence farmers under rainfed farming to plant these different crops at different times in order to maximize yield. Testing only four planting dates in one season cannot be conclusive so further serial experiments are important to ascertain the best planting date.

Chapter 5

Conclusions and Recommendations

5.1 Introduction

Farmers residing in marginal agricultural production areas continue to face increased risk to their crop production. While conditions in these areas have never been optimal for crop production, climate change and variability is now placing farmers' livelihoods at greater risk. Already, farmers are struggling to cope with the seasonal shifts in traditionally known onset of rainy season dates (Mabhaudhi 2012). This is also worsened by increased unevenness of rainfall distribution during the season. Under these conditions, crops are often exposed to water, heat and aeration stress at any time during their growth cycle; this often results in massive crop failure. It is known that certain crop growth stages are more sensitive to water stress than others. Therefore, hypothetically, selecting a planting date that can ensure that critical crop growth stages do not coincide with stresses could help ensure harvests. It was on the basis of this hypothesis that this study was conducted to evaluate the effect of planting date and crop selection on yield attainability.

5.2 Challenges

- During flood times it was not easy to carry out weeding and other operations as the plots were inaccessible due to muddy clay soil.
- There was a high incidence of maize stalkborer as a result of prolonged dry spells.

- There were incidents of hare / wild rabbits attacking dry beans plants. Nets had to be erected around the sub-plots.

5.3 Future Lessons and Research Possibilities

- The need to select the right planting time for best yields is unarguable hence further study to investigate and determine the range of time period of planting in Makhathini is necessary.
- Research to understand further mechanisms of water use by these crops (dry beans, maize and sweet potato) strengthen this experiment.
- The investigation of other agronomic crops and how they perform in Makhathini is another beneficial avenue in pursuit of improved yields in relation to planting date selection.
- The use of validated crop models could save on the cost and time of lengthy agronomic trials and be used as a decision support tool for assisting farmers. The training of undergraduate and postgraduate students, as well as extension officers on the use of decision support tools could prove beneficial to farmers.

5.4 Final Comments and Summary Conclusions

The study highlighted the economic importance of planting date selection as a management tool for maize, sweet potato and dry beans crop production in subsistence farming. The results of the present study will contribute in addressing the problem of yield loss and crop failure due to uninformed planting date selection practices among subsistence farmers of Makhathini community of Umkhanyakude district, KZN, South Africa. Planting at the right date enhances resource utilization and can benefit subsistence farmers when fertilizers such as nitrogen can only effectively be put to use by the crop during availability of water (Braunack *et al*. 2012). Lauer *et al*. (1999) reported that altering planting dates can be useful to manage water stress under rain-fed conditions with minimal yield loss. However, predicting planting dates in low latitudes is complex when only using climate data of South Africa (Sacks *et al*. 2010).

This study confirmed that variation in planting dates has an effect on growth, phenology and yield of maize, sweet potato and dry beans. The present study therefore recommends early planting of maize in order to escape yield losses due to drought stress. The study recommends a late season planting for dry beans in order to optimize yields. Supplementary irrigation is recommended for sweet potato during early establishment stage. Farmers should also be advised about exploiting drought tolerant varieties as a drought mitigation strategy. Rain harvesting during flash floods is recommended; harvested water could then be used to provide supplementary irrigation during dry spells. Rain harvesting technologies are low cost interventions which require minimum maintenance as opposed to dam construction. The use of climate smart agriculture principles is encouraged to prevent soil degradation due to erosion occurring during flash floods.

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List of Appendices

Appendix 1: Maize

Variate: %_Emergence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	145.42	72.71	2.67	
Rep.*Units* stratum					
Planting_date	3	551.34	183.78	6.75	0.002
DAP	2	56023.03	28011.52	1028.91	<.001
Planting_date.DAP	6	2367.93	394.65	14.50	<.001
Residual	22	598.94	27.22		
Total	35	59686.66			

Variate: Height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	494.0	247.0	0.60	
Rep.*Units* stratum					
Planting_date	3	34416.0	11472.0	27.82	<.001
DAP	16	413293.7	25830.9	62.63	<.001
Planting_date.DAP	48	157538.1	3282.0	7.96	<.001
Residual	134	55262.6	412.4		
Total	203	661004.4			

Variate: Leaf_No

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	19.06	9.53	0.33	
Rep.*Units* stratum					
Planting_date	3	251.38	83.79	2.94	0.036
DAP	16	4584.33	286.52	10.04	<.001
Planting_date.DAP	48	2049.39	42.70	1.50	0.038
Residual	134	3822.77	28.53		
Total	203	10726.92			

Variate: Fresh_biomass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	53246.	26623.	1.69	
Rep.*Units* stratum					
Planting_date	3	2210338.	736779.	46.89	<.001
DAP	6	2777582.	462930.	29.46	<.001
Planting_date.DAP	18	7979792.	443322.	28.21	<.001
Residual	57	895715.	15714.		
Total	86	13888253.			

Variate: dry_biomass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	14360.	7180.	1.96	
Rep.*Units* stratum					
Planting_date	3	379886.	126629.	34.61	<.001
DAP	6	518801.	86467.	23.63	<.001
Planting_date.DAP	18	1538791.	85488.	23.37	<.001
Residual	57	208539.	3659.		
Total	86	2655191.			

Variate: Time_to_seedling_establishment

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	4.5000	2.2500	2.45	
Rep.*Units* stratum					
Planting_date	3	8.2500	2.7500	3.00	0.117
Residual	6	5.5000	0.9167		
Total	11	18.2500			

Variate: time_to_maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	57.17	28.58	2.33	
Rep.*Units* stratum					
Planting_date	3	21768.25	7256.08	592.33	<.001
Residual	6	73.50	12.25		

Total	11	21898.92			

Variate: time_to_silking

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	26.167	13.083	1.85	
Rep.*Units* stratum					
Planting_date	3	12768.250	4256.083	600.86	<.001
Residual	6	42.500	7.083		
Total	11	12836.917			

Variate: time_to_tasseling

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	8.17	4.08	0.27	
Rep.*Units* stratum					
Planting_date	3	142.92	47.64	3.18	0.106
Residual	6	89.83	14.97		
Total	11	240.92			

Appendix 2: Dry beans

Variate: %_Emergence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	136.71	68.35	2.13	
Rep.*Units* stratum					
DAP	2	22636.48	11318.24	352.48	<.001
Planting_date	3	9505.85	3168.62	98.68	<.001
DAP.Planting_date	6	10296.04	1716.01	53.44	<.001
Residual	22	706.44	32.11		
Total	35	43281.51			

Variate: Height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	173.51	86.75	7.61	

Rep.*Units* stratum					
Planting_date	3	13313.92	4437.97	389.49	<.001
DAP	13	7646.10	588.16	51.62	<.001
Planting_date.DAP	39	9268.65	237.66	20.86	<.001
Residual	110	1253.37	11.39		
Total	167	31655.54			

Variate: Leaf_No

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	925.88	462.94	6.45	
Rep.*Units* stratum					
Planting_date	3	25955.04	8651.68	120.63	<.001
DAP	13	32866.67	2528.21	35.25	<.001
Planting_date.DAP	39	27906.37	715.55	9.98	<.001
Residual	110	7889.39	71.72		

Total 167 95543.35

Variate: Dry_mass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.661	0.330	0.05	
Rep.*Units* stratum					
Planting_date	3	786.018	262.006	38.78	<.001
DAP	4	340.538	85.135	12.60	<.001
Planting_date.DAP	12	1755.829	146.319	21.65	<.001
Residual	38	256.762	6.757		
Total	59	3139.808			

Variate: Fresh_mass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	29.55	14.77	0.20	
Rep.*Units* stratum					
Planting_date	3	8063.97	2687.99	35.71	<.001
DAP	4	5920.98	1480.24	19.66	<.001
Planting_date.DAP	12	24281.88	2023.49	26.88	<.001
Residual	38	2860.56	75.28		

Total 59 41156.94

Variate: time_to_emergence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.000	0.000		
Rep.*Units* stratum					
Planting_date	3	147.000	49.000		
Residual	6	0.000	0.000		
Total	11	147.000			

Variate: time_to_flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00	0.00		
Rep.*Units* stratum					
Planting_date	3	7166.25	2388.75		
Residual	6	0.00	0.00		
Total	11	7166.25			

Variate: time_to_maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	8.167	4.083	1.00	
Rep.*Units* stratum					
Planting_date	3	24414.250	8138.083	1993.00	<.001
Residual	6	24.500	4.083		
Total	11	24446.917			

Variate: time_to_podding

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	906.5	453.2	0.88	
Rep.*Units* stratum					
Planting_date	3	11596.7	3865.6	7.53	0.019
Residual	6	3078.8	513.1		
Total	11	15582.0			

Variate: Hundred grain_seed_mass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.3333	0.6667	1.00	
Rep.Planting_date stratum					
Planting_date	1	42.6667	42.6667	64.00	0.015
Residual	2	1.3333	0.6667		
Total	5	45.3333			

Variate: No_Of_pods

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	23.749	11.875	2.89	
Rep.Planting_date stratum					
Planting_date	1	35.852	35.852	8.72	0.098
Residual	2	8.227	4.113		
Total	5	67.828			

Variate: Seeds_per_pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.804	1.902	1.13	
Rep.Planting_date stratum					
Planting_date	1	13.650	13.650	8.08	0.105
Residual	2	3.379	1.689		

Total 5 20.833

Appendix 3: Sweet potatoes

Variate: Leaf_No

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	164430.	82215.	10.19	

Rep.*Units* stratum					
Planting_date	1	206612.	206612.	25.60	<.001
DAP	19	275888.	14520.	1.80	0.038
Planting_date.DAP	19	287711.	15143.	1.88	0.028
Residual	78	629613.	8072.		
Total	119	1564253.			

Variate: Height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	88576.	44288.	16.70	
Rep.*Units* stratum					
Planting_date	1	141158.	141158.	53.22	<.001
DAP	19	68982.	3631.	1.37	0.168
Planting_date.DAP	19	119393.	6284.	2.37	0.004
Residual	78	206899.	2653.		
Total	119	625009.			