WATER USE AND NUTRITIONAL WATER PRODUCTIVITY OF TARO (*COLOCASIA ESCULENTA L. SCHOTT*) LANDRACES

by

Sihle Cyril Shelembe

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College of Agriculture, Engineering and Science

University of KwaZulu-Natal

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PREFACE

The research contained in this thesis was carried out 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, from April 2018 to April 2020 under the supervision of Professor Albert T. Modi. The research was financially supported by the Moses Kotane Research Institute (MKI) together with the Water Research Commission (WRC) of South Africa through WRC Project No. K5/2493//4 ‘Water use of crops and nutritional water productivity for food production, nutrition, and health in poor rural communities.’

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.

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AT Modi (Supervisor)

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DEDICATION

This thesis is dedicated to the memory of my beloved late niece, **Sisipho Shelembe** who regretfully did not live that long to see this work!

DECLARATION

I, Sihle Cyril Shelembe, 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;

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

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(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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Sihle Cyril Shelembe (Student)

LIST OF ABBREVIATIONS

AIDS - Acquired Immunodeficiency Syndrome

AWS - Automatic Weather Stations

CBDV - *Colocasia* Bobone Disease Virus

CCI - Chlorophyll content index

CEF- Controlled Environment Facility

CF - Chlorophyll fluorescence

CRD - Completely Randomized Design

CV - Coefficient of Variation

DAFF- Department of Agriculture Forest and Fisheries

DAP - Days After Planting

DsMV- Dasheen Mosaic Virus

ETa- Crop Water Requirement

ETo – Average Reference Evapotranspiration

FAO - Food and Agriculture Organisation

FAOSTAT - Food and Agriculture Organization Corporate Statistical Database

HI - Harvest Index

HIV - Human Immunodeficiency Virus

Kc – Crop Coeffiecnt

KZN - KwaZulu-Natal

LSD – Least Significant Difference

MG - Mgingqeni

NC - Nutritional Content

NUCS – Neglected and Underutilised Crop Species

NWP – Nutritional Water Productivity

PAR - Photosynthesis Active Radiation

PI - Pitshi

RH - Relative Humidity

SA - South Africa

SC - Stomatal Conductance

SDG - Sustainable Development Goal

SIWI - Stockholm International Water Institute

SSA - Sub-Saharan African

SWC - Soil Water Content

TaBV- Taro Bacilliform Virus

UKZN - University of KwaZulu-Natal

UM – Umbumbulu

UN - United Nations

USA - United States of America

WAP - Weeks after Planting

WP – Water Productivity

WUE – Water Use Efficiency

ABSTRACT

Taro (*Colocasia esculenta*) is a vital drought tolerant crop with the ability to produce corms of high nutritional quality, but it still occupies low levels of utilisation and research in South Africa. Information on crop agronomy, management practices and water use has been limited and not available to farmers. The study aimed at determining the response of taro landraces to water availability under controlled environment conditions in a growth chamber. Further, the crop response to dryland conditions during the 2018 and 2019 growing seasons was observed. Under field conditions, the experimental factors were planting date and fertiliser level. The eddo type taro landraces were all collected from rural areas of KwaZulu-Natal. For controlled environment facility (CEF), the experimental design was arranged as a randomized complete block design (RCBD) and replicated three times, with three factors: temperature(~33/18°/C day/night; 60–80% RH), water regimes (30% and 100% of crop water requirement (ETa) and taro landrace. For field trials, a factorial design in randomized complete block design (RCBD) with three replications was conducted. Three experimental factors were examined namely; planting dates (October, November and December), three organic fertilisers (0, 160 and 320 N kg per hectare) and two taro landraces MG and PI. The CEF results revealed that better relative growth and development were associated with better corm starch content and this occurred more at 100% compared with 30% ETa. However, water use efficiency (WUE) and nutritional water productivity were found to be higher in response to 30% ETa compared with 100% ETa. The results of the field trial indicated that planting date and fertilisation have a significant effect on crop establishment, growth parameters, actual yield and yield parameters, mineral, starch, and moisture content. The yield parameters were decreased by delaying planting but increased by organic fertiliser. The corm mineral content increased by organic fertiliser application, but the starch content was decreased. It is concluded that taro growth and corm size will increase in response to water and nutrient availability, but the nutritional value of the corm may be compromised.

Keywords: *Taro, water use, planting date, fertilisation, yield quality*

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CHAPTER 1

INTRODUCTION

1.1 Introduction and Motivation

South Africa is known to be producing enough food to feed its population at national level (Du Toit *et al*. (2011). However, 26% of the population is still regarded to be food insecure at the household level, while 28.3% is prone to the risk of food insecurity (van der Berg, 2006; Abdu-Raheem and Worth, 2011; Shisana *et al*., 2013; Walsh and Van Rooyen, 2015). Agriculture has been identified as a solution to improve food security; but the major issue is that South Africa is considered as water-scarce and one of the semi-arid countries in the world (Donnenfeld *et al*. 2018). In recent years, studies have revealed low water availability and climate variability and change as important contributors that threaten the productivity of agriculture in South Africa. Other factors that threaten food security at the household level include high poverty levels, increased population, poor health, macroeconomic imbalances, and environmental degradation (Smith *et al*., 2000; Clarke and King 2005; Abdu-Raheem and Worth, 2011). Thus, there is a need to improve on scientific research knowledge, to enhance technologies that could use less water to achieve high food output using underutilised crops (Abdu-Raheem and Worth, 2011).

Neglected and underutilised crop species (NUCS) are defined as crops that have not received enough recognition as major crops in the past, with less previous scientific research and they currently occupy low levels of utilisation mainly cultivated by smallholder farmers that are based in the rural areas (Azam-Ali, 2010). Unlike most staple crops, NUCS have the ability to adapt well under local growing conditions ensuring sustainable food production and food security. However, these conditions are often characterised as severe and harsh (Padulosi *et al*., 1999; Idowu, 2008; Lebot, 2009). In the past, NUCS had played a vital role in the region of Sub-Saharan Africa (SSA), particularly in water-scarce countries.They were used as an alternative in providing healthy food and ensuring that food and nutrition were improved at the community and household level when the main crops failed to produce enough food (Mabhaudhi *et al*., 2011). As a result, this makes them essential within South Africa, where the water-scarce condition affects agriculture and food security. The introduction of crops such as taro [*Colocasia esculenta (L.) Schott*] has been recommended as a solution in improving food and nutrition security and productivity under low water availability (Aregheore and Perera, 2003; Mabhaudhi, 2012; Mabhaudhi *et al*., 2014; Chivenge *et al*., 2015). However, as water availability continues to be a limiting factor to crop production, more research needs to be done on understanding adaptation mechanisms for taro production.

The adoption of taro and other NUCS into existing cropping systems has been low. This has been attributed, in part, to limited availability of scientific knowledge describing their aspects of agronomy, water use, and nutritional productivity (Mabhaudhi *et al*., 2014; Chivenge *et al*., 2015). Therefore, the promotion of NUCS with the idea of using them as an alternative food source in agriculture will depend more on improving scientific research describing their agronomy, water use and nutritional productivity, including value addition and assist farmers in having access to the markets (Chivenge *et al*., 2015). Recent agronomy studies on NUCS such as taro regarding the planting date reported that early planting date leads to higher yield with high nutrition due to high rainfall available in the season, as compared to late planting with low rainfall available (Mare, 2009; Mare and Modi, 2012). Thus, such information could be pivotal to farmers who are willing to increase taro production, with high nutrition while applying less water to their crops. Therefore, it is considered essential that we begin to study available local NUCS and identify mechanisms that allow for drought tolerance. We can enhance adaptability by using different agronomic techniques while monitoring the nutritional value (Mabhaudhi, 2012; Mabhaudhi and Modi, 2013). This study aimed to evaluate water use and nutritional water productivity of taro (*Colocasia esculenta L. Schott*) landraces. The following specific objectives were formulated to test the null hypothesis and address study objectives:

- To determine the effect of different water levels on growth, development, yield, WUE, WP and NWP of a single taro landrace under controlled environment conditions.
- To investigate the effect of planting date and fertilisation on growth, development and yield quality of taro landraces found in Umbumbulu, KwaZulu-Natal, under dryland field environmental conditions.

1.2 Hypothesis

- Null Hypothesis: There is no statistically significant difference between the levels of starch present at 30% compared to 100% crop water requirement.
- Alternative hypothesis: The application of different water levels and different planting dates will influence the final yield and nutrition of taro landrace.

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CHAPTER 2

LITERATURE REVIEW

2.1 Botany and Ecology

2.1.1 Classification and genetics of Taro

There are many tuber and root crops grown in the world and taro [*Colocasia esculenta (L.) Schott*] is one of the most consumed vegetable crops by many people around the world. Taro is a perennial monocotyledonous herb that falls under Araceae, the family of the sub-family Aroideae, whose members are generally known as aroids (Lee, 1999; Onwueme, 1999; Lebot, 2009; Mabhaudhi, 2012). Taro belongs to the genus *Colocasia*, within the sub-family Colocasioideae of the monocotyledonous family Araceae (Onwueme, 1999). Araceae is a large family, consisting of a hundred genera even larger than fifteen hundred species (Lee, 1999; Mandal *et al*., 2013; Macharia *et al*., 2014; Banjaw, 2017).

Colocasia esculenta var esculenta and *Colocasia esculenta var antiquorum* are the two most widely cultivated taxonomic taro varieties around the world (Tumuhimbise, 2016; Ubalau, 2016; Banjaw, 2017). Purseglove (1972), Lebot and Aradhya (1991), Mare (2009) and Banjaw (2017) have agronomically classified *Colocasia* species as dasheen and eddoe type, where dasheen type the (*Colocasia esculenta (L) Schott var. esculenta*) are known to produce large cylindrical central corm with very few cormels. The eddoe type (*Colocasia esculenta (L) Schott var. antiquorum*) is characterised as the one producing small globular central corm surrounded with many side cormels (Purseglove, 1972; Lebot and Aradhya, 1991; Mare, 2009; Banjaw, 2017). The dasheen type is reported to be one of the most grown taro varieties in the region of Asia/Pacific (Onwueme, 1999).

There are different agronomic cultivars of taro grown around the world; approximately hundreds of taro cultivars (Onwueme, 1999). All cultivars are classified according to their cormel, corm, shoot characteristics, and perhaps based on agronomic behaviour (Onwueme, 1999). Some of the local taro landraces in KwaZulu-Natal (KZN) belong to the genus *Colocasia* and species *esculenta* (Mare, 2006; Mabhaudhi, 2012). During the past centuries, just before the exchange of global crops, taro was recognized as one of the starch crops being widely cultivated in the world (Matthews, 2006). Taro genotypes that are available and grown are characterised into cultivated and wild type (Onwueme, 1999; Banjaw, 2017).

According to Quero-Garcia *et al*. (2006) and Banjaw (2017), the wild type genotype of taro is not suitable to be used as food, especially for humans, as the corms contain a very high concentration of calcium oxalate crystals. The cultivated type genotype of taro is characterised as the *Colocasia esculenta;* however, the species is regarded as polymorphic (Onwueme, 1999). The long history of vegetative propagation has created some confusion and debate with regards to taxonomy involving the genus *Colocasia* (Onwueme, 1999). Therefore, in terms of tilling conditions of the corm, taro is mainly categorized into three genotypes, namely; dasheen, eddoe and the polycephalous type (Onwueme, 1999; Wang *et al*., 2017).

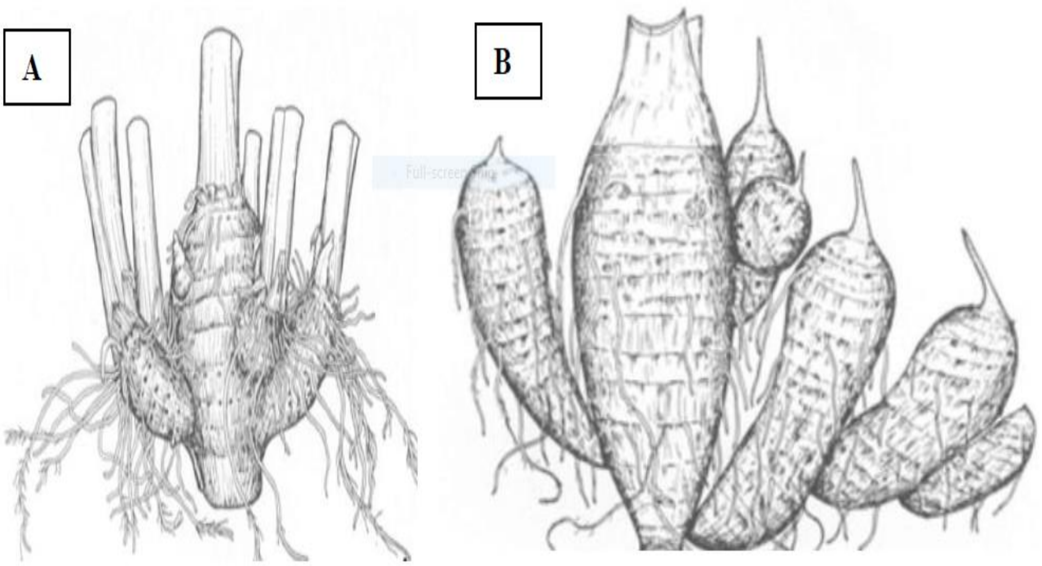

Figure 2.1: Diagram showing the dasheen [A] and eddoe [B] type of taro landrace (Sibiya, 2015).

Figure 2.1 indicates the structure of the dasheen and eddoe type of taro. The dasheen is classified in terms of producing single or many well-developed mother corms containing fewer and smaller daughter corms (Onwueme, 1999). And the eddoe type is classified according to producing poorly developed mother corm with grouped daughter corms (Onwueme, 1999).

2.1.2 Origin and distribution

Taro is believed to have originated from tropical America and Asia (Mabhaudhi and Modi, 2013). Many researchers such as Lebot (2009), have studied and attempted to review the place of origin for taro, as the uncertainty remains about the place of origin (Yen and Wheeler, 1968;

Plucknett, 1984; Matthews, 1990; Lebot and Aradhya, 1991; Lebot, 1999). However, the discussion remains still about the place of origin for taro where, all ethno-botanical evidence points that taro came from South Central Asia, even possibly in India or the Malay Peninsula (Spier, 1951; Onwueme, 1999; Modi, 2004; Shange, 2004; Sibiya, 2015). Previous findings have indicated that there is no single place of origin for taro (Mabhaudhi, 2012). However, Lebot (2009) believed that the main centre of origin for taro was tropical Asia, even though some species are believed to have originated in different places of the world. Taro is characterised as a neglected underutilized crop species (NUCS), and it is ranked fourteenth among staple vegetable crops globally, where approximately 2 million hectares of land is allocated to the crop cultivation and producing about 12 million tonnes (Rao *et al.*, 2010; Mabhaudhi, 2012). Most of the taro production is more taking place in Africa, with an average yield estimated to be 6.5 tons per hectare (FAOSTAT, 2012; Mabhaudhi, 2012).

Taro is mainly considered as one of the oldest crops known to man (Mabhaudhi, 2012). It is estimated to have existed on earth for about a period range of 9 000 to 10 000 BC until today taro has spread to different places of the world, from its centre of origin where it is cultivated (Lebot, 2009; Rao *et al*., 2010). Taro has spread to places such as South East Asia, Japan, China, as well as the Pacific Islands, where it is now mostly cultivated (Purseglove, 1972). Most of the wild type of taro is found and located in many parts of South Asia (Onwueme, 1999). During the period of 100 B.C, most of the taro production was practiced in Egypt and China (Purseglove, 1972). Most of the taro production has spread from Asia to many places in the world, including westward to Arabian and the Mediterranean region. However, the spreading of taro continued and over a period of 2000 years ago, it has reached the east coast of Africa, where it was taken by voyagers (Onwueme, 1999). It first spread across the continent towards West Africa, and after that, it reached on slave ships to the Caribbean (Onwueme, 1999).

Currently, taro is classified as pan-tropical in terms of its distribution and cultivation. According to Onwueme (1999), West Africa is considered the largest part of the world for taro cultivation, in which it represents the largest quantity of production. The eddoe type has been known as a variety that was transformed from the cultivated taro in Japan and China many centuries ago, where it was distributed to the West Indies as well as to the rest of the world (Purseglove, 1972). A high quantity of taro cultivation together with high volume contribution to a human diet mainly takes place in the Pacific Islands. Other relevant cultivars of taro are being grown in the Caribbean and further to humid either sub-humid parts of Asia (Onwueme, 1999).

In Africa, taro is reported to have spread throughout the continent due to trade and migration (Mabhaudhi, 2012). In most parts of South Africa (SA), taro is classified as the traditional "indigenised" crop and is mainly grown by rural farmers within the area province of KZN (Mabhaudhi, 2012; Naidoo *et al*., 2015). Taro, especially in KZN, is known in Zulu as amadumbe; other common names are amadumbi, amadombie, amadombi and mufhongwe (DAFF, 2011; Lewu *et al*., 2017). Taro is one of the important staple crops, especially in KZN, to sub-tropical coastal areas from Bizana in the Eastern Cape towards the coastal areas of KZN (Mabhaudhi, 2012). However, a small portion is also cultivated in the sub-tropical and tropical areas of Limpopo and Mpumalanga provinces (Shange, 2004). Therefore, taro cultivation, together with consumption, continues to remain low, especially within the developing countries, even though taro tubers are cooked and eaten the same way as tuber crops such as the potato (Lewu *et al*., 2017).

2.1.3 Morphology and anatomy

Taro is one of the naturally perennial herbaceous crops, which is harvested at about 5-12 months of growth (Mare, 2006; Mwenye, 2009; Banjaw, 2017). Taro is reported can grow to a height of about 0.5 -2 meters (Miyasaka *et al*., 2003; Mare, 2006; Deo *et al.*, 2009; Sibiya, 2015). The main plants have the ability to produce side suckers that can grow to a height of 40-100 cm (Sibiya, 2015). During the growth of taro, a corm is formed which is lying under the soil surface with the leaves growing upwards, and the roots growing downwards while cormels daughter corms and runners grow laterally shown in Figure 2.2 below (Ubalua *et al*., 2016; Banjaw, 2017). According to Matthews *et al*. (2012), taro consists of heart-shaped leaves with long petioles, characterised by fibrous roots and cylindrical nutrients storage organ considered as a corm. The root system normally lies in the top one meter of the soil (Joubert and Allemann, 1998).

The large heart-shaped leaves are the only part that is visible above the ground and use to determine plant height in the field (Onwueme, 1999; Mare, 2006). Reported by Sibiya (2015), the heart-shaped green leaves are 20-50 cm in length joined on leaf stems with a diameter of

30-90 cm. The leaf blades of taro are connected from the top of long petioles showing as clusters from the corms (Ezumah, 1972; Van Wyk, 2005; Mare, 2006). The petiole is possessed as very thick at the base, while it is thinner along to its attachment to the lamina (Mare, 2006). The internal structure of the petiole is characterised as being spongy in texture, containing many air spaces that are helpful in controlling gaseous exchange when planted under swampy environments. For many taro varieties, the attachment of the petiole is observed not at the edge of the lamina and perhaps at some point in the middle (Mare, 2006). The lamina of taro is egg-shaped about 20-50 cm long, with the basal lobes rounded (Sibiya, 2015).

Taro can be normally propagated vegetative from the suckers; however, the plant is able to produce flowers and set seed (Wang, 1983; Chand *et al*., 1998; Kreike *et al*., 2004, Sibiya 2015). Flowers are relatively smaller and rarely produced naturally together with the fruits; they are normally crowded on the upper part of the fleshy stalk (Wang, 1983; Van Wyk, 2005; Deo *et al*., 2009). According to Ivancic *et al*. (2004) and Banjaw (2017), emphasized on using plant physiology and modern breeding technologies to improve sexual reproduction, since taro is known to have poor flowering. However, flowering can be induced artificially using gibberellic acid (Van Wyk, 2005). The female flowers are found below with the male flowers being above, and fruits are observed in small berry, in clusters on the fleshy stalk (Onwueme, 1999; Sibiya, 2015). During the inflorescence, taro flowers contain a cylindrical spadix shape of flowers, which are surrounded in a 12-15 cm spathe resulting in unisexual with the female flowers found at the base of a spadix with the male flowers at the top (Castro, 2006; Banjaw, 2017). The inflorescence normally occurs from the centre of the cluster of unexpanded leaves (Mare, 2006). In taro, each plant is capable of bearing more than one inflorescence and it is made up of a short peduncle, a spadix, and spathe (Mare, 2006).

The spadix is characterised as being botanically a spike consisting of a fleshy axis where the small sessile flowers are attached (Mare, 2006). The size of the spadix is believed to be 6-14 cm long with sterile flowers attached in between of female and male flowers, within the region that is compressed by the neck of the spathe (Banjaw, 2017). According to Onwueme (1999), the tip part of the spadix is characterised to have no flowers completely, which is called the sterile attachment. The spathe is approximately 20 cm in length with a large yellowish bract. Female flowers are totally obstructed from view; through that, the lower portion of the spathe is located tightly around the spadix. The process of pollination in taro is primarily achieved by flies, in order to induce fruit and set seed production normally under natural conditions (Mare, 2006). Whenever fruits are produced, they normally arise from the lower position of the spadix. Fruits produced contain many seeds, where the fruit size is about 3-5 mm in diameter. Within the seed, there is a hard testa, which consists of endosperm in addition to the embryo (Onwueme, 1999; Mare, 2006).

Furthered by Doe *et al*. (2009), taro consists of enlarged, starchy, underground stems that are well labelled as corms. The corms are being observed as highly inconstant concerning hydration, colour, size, and chemistry (Sibiya, 2015). The formation of the corm is outward, composed of concentric rings containing leaf scars and scales. Taro corms produce side suckers called secondary cormels small in size, which mainly comes from lateral buds found under each leaf base (Onwueme, 1978; Sibiya, 2015). These cormels are produced in a different shape from spherical to elongated with an approximate diameter of 15 to 18 cm, where the tuber physical structure is made up of thick, brown outer covering within which lies the starch-filled ground parenchyma (Wang, 1983).

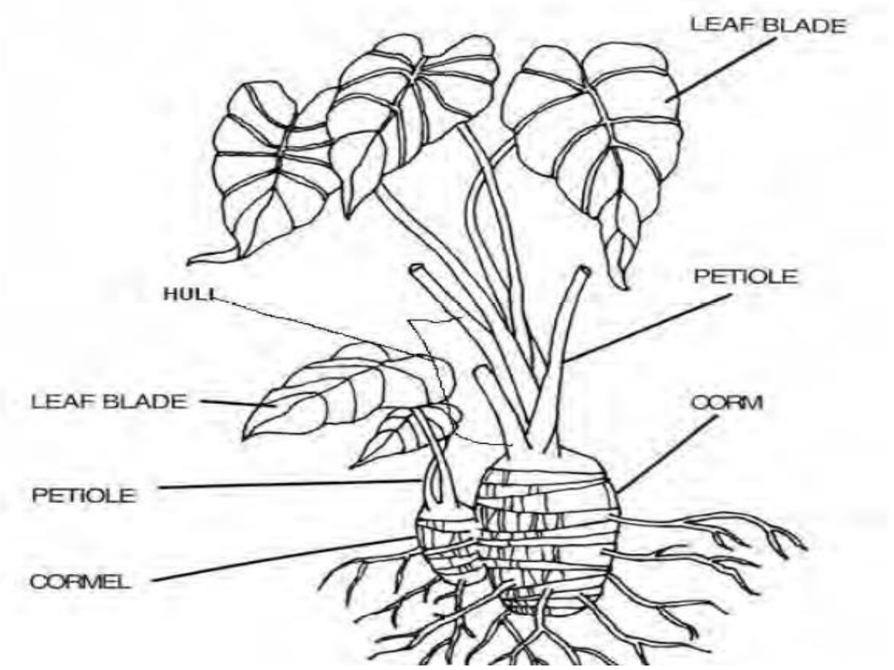

Figure 2.2: Diagrammatic taro plant showing leaves, corms, cormels and suckers (Miyasaka *et al*., 2003).

The dasheen types of taro are characterised as having cylindrical corm that is 30 cm long in size and 15 cm in diameter, consisting of the essential edible part of the main plant (Sibiya, 2015). However, the eddoe types are different from dasheen, where they contain small, globoid, and surrounded by many cormels and daughter corms (Onwueme, 1978). In eddoe type of taro, the cormels and daughter corms both form an essential portion of the edible harvest. According to Onwueme (1978) and Sibiya (2015), believe that daughter corms are relevant dormant and will result in new shoots if left in the ground after harvesting the main plant.

2.1.4 Utilisation and composition

Tubers are known to be a vital source of carbohydrates in terms of energy source, and they are being utilised as staple foods in many of the regions of tropical and subtropical countries (Kaushal *et al.*, 2015). Before consumption, they undergo a different form of process, which allows for easy digestibility and which also helps in reducing postharvest losses resulting in an increase in shelf life (Liu *et al.*, 2006). Taro is one of the roots and tuber crops characterised as an underutilised but consists of good economic value. However, Liu *et al.* (2006) emphasized that developing advanced and suitable technology could be one of the factors used in increasing the utilisation of taro.

Taro has three main economic parts, which contribute to its economic values and those include corms, cormels and leaves (Onwueme, 1999; Vinning, 2003). As indicated from Table 2.1, tubers are a good source of carbohydrates and taro corms are an excellent source of carbohydrates, and also taro known to contain low levels of fat and protein, while the leaves contain good levels of carotene and potassium (Lambert, 1982; Hanson and Imamuddin, 1983; Bradbury and Holloway, 1988; Mare, 2006). Tubers of tropical plants known to belong to the Araceae family have the capacity to store high concentration of starch that is approximately 22-40 % (Delpeuch *et al.*, 1978; Rashid and Daunicht, 1979; Treche and Guion, 1980; Agbor Egbe and Rickard, 1990; Mare, 2006).

Tuber and root crops contain approximately 16-24 % of carbohydrates which is essential for the human body (Hizukuru *et al.*, 1970; Muhrbeck and Tellier, 1991; Nielsen *et al.*, 1994; Mare, 2006). However, Table 2.1 shows that taro contains about 19%, 12.2% and 4.6% of carbohydrates for corms, leaves, and petioles, respectively. From Table 2.1, taro corms are indicated as the 100g^{-1} edible portion with more carbohydrates (53.1%) compared to the leaves and petioles with 34.1% and12.8% respectively. Taro is also known to have a starch level that is approximately 70-80% (TU *et al.*, 1979; Modi, 2004). A study by Onwueme and Charles

(1994) showed that within 13-29% of fresh corm carbohydrates, 77.9% is classified as starch. Vinning (2003), also mentioned that taro corms contain up to 35% level of starch. When eaten regularly taro corms, they tend to provide a good source of energy, fibre, calcium and iron, which is good and healthy for a human body (Aregheore and Perepa, 2003; Van Wyk, 2005, Mare, 2006). According to Van Wyk (2005), consumption of taro provides good benefits such as good levels of phosphorus and vitamin C, which is important for the human body. While Table 2.1 shows high levels of phosphorus (100g per edible portion) on the leaves with 47.3% compared to the corms with 38.8% and petioles with 13.9% of the total percentage of phosphorus.

Taro is one of the crops that contain more starch within the tuber and roots crops, containing approximately 80% amylopectin with 22 glucose units per molecule and 20% amylose with 490 glucose units per molecule (Mae, 2006). Onwueme (1999) and Van Wyk (2005) stated that taro produces very small starch grains that improve and easy for digestibility. However, small starch granules make taro the essential and suitable food mainly for people with allergies and some disorders, and it is also relatively good to those with cereal allergies as well as animal milk (Onwueme, 1999; Vinning, 2003). Evidence points out that taro has a very high percentage of starch digestibility, estimated at approximately 98% (Vinning, 2003). Taro starch is normally not used for industrial starch due to its very small starch grains (Onwueme, 1999). Taro can be suitable to be eaten when cooked with the skin or without the skin (Vinning, 2003; Mare, 2006). Most of the taros are cooked in order to eliminate the irritation before eating (Hutton, 2004).

The size of taro starch granules differs, and it approximately varies from 1.0-6.5 micrometres and as a result, the starch that is found within taro is also useful when making plastic grocery bags in order to improve biodegradability (Llamas, 2003). The protein content found in taro vary from 1.0-4.5%, and Table 2.1 shows the leaves as the part that contains more protein content about 4.4 g while the corm and the petiole contain 2.5 and 0.2 respectively per 100 g edible portion (Kaushal *et al*., 2015). Taro is known to cause severe rash due to allelopathic characteristics as well as irritating calcium crystals exhibited by taro (Perdales and Dingal, 1988; Vinning, 2003; Mare, 2006). Huang *et al*. (2007) reported factors contributing to the nutritional composition of root and tuber crops are mainly by climate and species. It has also been reported that other factors contributing to phosphorus content of root and tuber crops include the temperature together with the growing environment (Hizukuru *et al.*, 1970; Muhrbeck and Teller, 1991; Neilsen *et al.*, 1994; Mare, 2006).

Table 2.1: Nutritional composition of the fresh taro corm (Kaushal *et al.*, 2015).

	Components per 100 edible portions		
	Corms	**Leaves**	**Petioles**
Edible portion (%)	81	55	84
Energy (cal)	85	69	19
Moisture (%)	77,5	79,6	3,8
Protein (g)	2,5	4,4	0,2
Fat (g)	0,2	1,8	0,2
Carbohydrates (g)	19	12,2	4,6
Fibre (g)	0,4	3,4	0,6
Calcium (mg)	32	268	0,6
Phosphorus (mg)	64	78	57
Sodium (mg)	7	11	23
Potassium (mg)	514	1237	5
Iron(mg)	0,8	4,3	367
Vitamin A (IU)	Trace	20385	1,4
Thaimine (mg)	0,18	0,1	335
Riboflavin (mg)	0,04	0,33	0,01
Niacim (mg)	0,9	2	0,02
Ascorbic acid Vitamic C (mg)	10	142	8

2.1.5 Growth cycle and development stages

The length of the growing season of taro is determined and influenced by different factors, including management practices, environmental conditions, as well as socio-economic factors (Singh *et al.*, 1998). Therefore, to accurately predict the correct time period of maturity is one of the most difficult management activities to put into practice. The normal growth rate of taro is initially very slow, but after 1-2 months of planting, plant growth increases rapidly (Onwueme, 1999). According to Westhuyzen (1967), Young (1992) and Shange (2004), SA upland taro that is customarily grown under dryland conditions harvested after a period of seven to eight months mainly during April and May exhibit such characteristics. The quality of taro corm, which displays the size and shape is normally determined at different stages of growth. Taro growth stages are being characterised into three different stages, as shown in Figure 2.3, namely establishment, vegetative growth, and corm initiation and bulking through maturation (Mare, 2009; Sibiya, 2015). Shown in Figure 2.3, the establishment stage for taro takes approximately 0-8 weeks after planting (56 days). In comparison, the vegetative stage takes about 8-20 weeks after planting (84 days), which is the stage for the formation of leaves and roots. The last stage, which is the maturity stage, takes about 20-40 weeks after planting (140 days), and that is the stage for corm initiation and bulking through maturation.

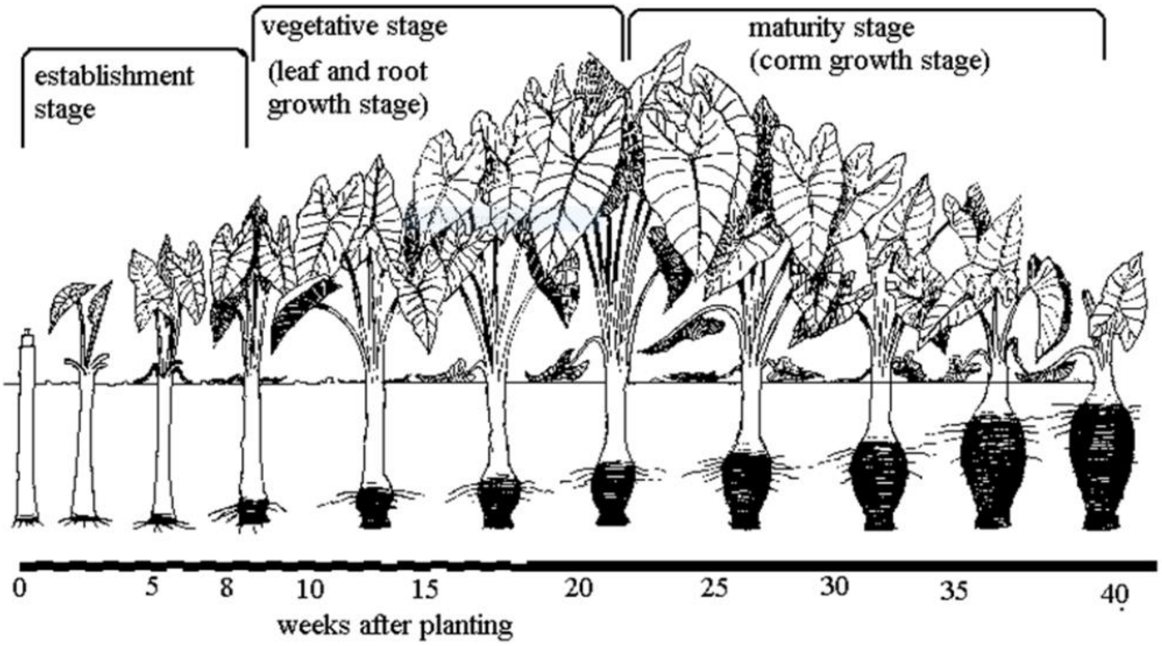

Figure 2.3: Taro Diagram showing different stages of growth (Singh, 1992).

The stage of establishment involves the formation of roots and leaf production (Sivan, 1982), and during this stage, sprouting and root growth starts to form. Modi (2007) emphasized on the importance of successful establishment as a critical factor to ensure proper crop production, which is mainly determined by propagule quality. Propagule size is one of the factors used in taro to determine successful establishment through that during this stage; the plants are receiving enough available carbohydrates from the seed throughout the plant leaf (Singh *et al*., 1998; Mare, 2009). However, large propagules have been reported to improve crop stand establishment in taro plants, which results in many plants reaching the third leaf stage as well as increase in leaf area per plant in a period of just one month after planting (Modi, 2007).

The stage of vegetative growth and corm initiation is the period characterised with rapid root and shoot development, where after two to four months, the initiation of corm starts to develop (Sivan, 1982; Mare, 2009). The stage is also characterised with slow corm growth, an increase in plant height, leaf area as well as an increase in the number of leaves (Silva *et al.,* 2008; Tumuhimbise *et al.,* 2009). During this stage, the leaf and stem are the critical parts to absorb nutrients required by the plant. A study by Goenega (1995) indicated maximal total leaf indices being reached at about 117 days after planting, then followed by a sharp decline. Furthered by Mare (2006) that plant height, leaf number, including the leaf area, were all able to reach the maximal at about 120 days just after planting. It is predicted that corm formation starts to form at about three months after planting, followed by cormel formation within the cultivars that can produce desirable cormels (Onwueme, 1999; Mare, 2009).

The stage of corm bulking, and maturation is normally the last stage before harvest. During this stage root and shoot, growth reaches the climax stage followed by a significant increase in corm development in approximately five to six months after planting and a senescence stage also approaching where root and shoot continue to decrease while increase in corm size continues at about six towards nine months (Sivan, 1982; Mare, 2009). At this stage, the plant growth is reduced together with a rapid decrease in leaf development (Silva *et al.,* 2008). It was also reported by Onwueme (1999) that shoot growth and total shoot dry weight indicated a rapid decline at about six months after planting. This was more influenced by a decrease in the number of active leaves, a decrease in the mean petiole length, including the total leaf area per plant, as well as in the mean plant height on the field (Mare, 2009).

A study by Goenega (1995) indicates that corm bulking normal occurs after reaching maximal leaf area indices, and just after 150 days after planting, the division of dry matter to the corms relatively remains constant throughout. It was also reported by Tumuhimbise *et al*. (2009), that the period of growth influences the corm diameter as well as a rapid increase in length throughout the 150 days. At this stage, the corms and cormels become the main consumers to the available nutrients and grow very rapidly (Singh *et al.,* 1998; Onwueme, 1999; Mare 2009).

Throughout the dry season, the corm and cormels allow the plant to survive and continue to grow. At this stage, if the plants are not harvested, they will grow new plants in the next favourable season through the process of sprouting (Mare, 2006). Furthered by Onwueme (1999), that if unfavourable condition does not prevail, the shoot will continue to grow for a period of years. It was also observed that just after six months of planting a decline in shoot growth, it was mainly influenced by a decline in leaf number, leaf area, petiole length and plant height (Ching, 1970; Johnston *et al*., 1997; Mare, 2006).

2.1.6 Availability and utilisation of taro in South Africa

Taro is a traditional crop within the area of KZN and is primarily known with a Zulu name amadumbe (Modi, 2004; DAFF, 2011; Lewu *et al*., 2017). Taro being classified as the traditional crop in most parts of SA, is mainly grown by rural farmers within the coastal area province of KZN (Naidoo *et al*., 2015). Taro is primarily grown for its edible corms containing equivalent nutrition as potato, where its mostly grown in tropical and also to subtropical areas throughout the world (Naidoo *et al*., 2015). In the subtropical coastal areas of SA, taro is viewed as an essential staple crop, and it is widespread from places such as the Bizana district in the Eastern Cape and the rest of coastal KZN (Mare, 2006). In SA, some of the taro (*Colocasia esculenta*) are cultivated on dry land (Naidoo *et al*., 2015). However, wild cultivated taro is reported with the poor formation of stolons that could result in low-quality yield (Naidoo *et al*., 2015).

There is relatively less cultivation of taro within the area of Midlands in KZN province, and there is believed to be none in the northern parts of the province because of an arid and colder climate (Shange, 2004). The crop is also cultivated in the subtropical and tropical areas of the Mpumalanga and Limpopo provinces (Shange, 2004; Mare, 2006). However, the crop occupies a low level of cultivation in SA due to the lack of scientific knowledge (Mabhudhi *et al*., 2013). Taro is mainly consumed in tropical areas, whereas daily nutrition is becoming less important and is slowly decreasing due to root crops such as sweet potato and cassava increasingly replacing taro (Lewu *et al*., 2017). Taro cultivation, together with its consumption, continues to remain low, especially within the developing countries, even though taro tubers are cooked and eaten the same way with tuber crops such as the potato (Lewu *et al*., 2017).

The cultivation of taro has been reported to have little importance in SA, whereby it is mainly cultivated by small-scale than commercial farmers (Mabhaudhi *et al*., 2014; Lewu *et al*., 2017).

In SA, most of the taro production is generally consumed as subsistence food on the farms (Shange, 2004; Mare, 2006). As most of the taro production is mainly consumed on the farms, only a small proportion finds its way to the market. However, within that small proportion, it has been mainly contributed by Umbumbulu farmers who are able to market their taro and sell it to Woolworths and Pick `n Pay, the largest retail stores in the country (Modi, 2003). Umbumbulu farmers are considered as possibly the only ones who have successfully commercialized the NUS in SA, resulting in more land allocated to taro production in KZN (Mabhaudhi, 2012). Mare (2006), believes taro is underutilised since only corms that are consumed as food, while the cooking of the leaves in SA is mainly not considered as a standard practice, but it is only consumed by the poor families. There are other benefits of consuming taro, and that includes helping children with digestive problems as well as supplementation of iron (Shange, 2004).

2.1.7 Uses and importance of taro

For a crop to be considered as adding value in a human diet, its nutritional value to a human body is one of the critical aspects to look out for. Tubers are vital for the human body through their availability of a good source of energy (Lewu *et al.*, 2010). Tubers are considered as healthy for human consumption as they are easily digestible containing an adequate amount of starch grain (Lewu *et al*., 2010). Taro is regarded as one of the staple foods, especially within the developing countries, mainly in Africa, the West Indies, and Asia through its rich source of carbohydrates and energy (Naidoo *et al*., 2015). Lee (1999), believes that taro is one of the tubers and root crops that is considered as a good source and a supplier of nutrients such as carbohydrates and potassium. Raw taro starch, which is digestible to humans, is reported to be equivalent to that of raw potato starch (Lee, 1999). The taro leaves are also recommended to be consumed by humans through high levels of nutrition. Taro leaves are essential for the human diet, especially when cooked as they contain nutrients that are equivalent to spinach (Lee, 1999). The taro leaves are known for providing adequate content of fibre, protein, dietary, vitamin and minerals (Lewu *et al*. (2010). Taro corms are identified not to have good source of ascorbic and carotene, however corms they contain carotene level that is almost the same as of the cabbage, but more than of a potato (Lee, 1999).

The cormels of taro contain an equivalent amount of starch as that of yam and sweet potato (Naidoo *et al*., 2015). Taro is a scarce major staple food since both parts of the plant can be consumed by humans, where the underground and leaf parts have been proven to be vital for the human diet (Lewu *et al*., 2017). Taro is regarded as a vital crop because of its position nutritional status and the value added by the crop in food security, especially in rural areas (Mare, 2009). Taro is generally cultivated through its edible fleshy tubers, which are corms, whereas the remaining part, including leaves, is consumed as green vegetables (Lewu *et al*., 2017). Taro leaves are consumed as vegetables through its high protein content available and the high balance of carbohydrates content present within the tubers (Mare, 2009). The digestibility starch level in taro is reported to be about 98.8 percent, while the level of starch grain present in taro is estimated to be one-tenth that of a potato (Lee, 1999). Taro, as mentioned, is also useful and recommended to people and children with allergies to cereals and milk, whereas greater vitamin content present in taro helps in preventing tooth decay (Lee, 1999).

Taro could be easily prepared and eaten the same way as other tuber and root crops like potatoes (Budi and Jenishinn, 2009). The main primary use of taro is mainly the consumption of its edible corms and leaves, and they are also characterised as a good source of iron, potassium, phosphorus, carotene, and calcium (Deo *et al*., 2009; Sibiya, 2015). The edible corms have high importance to the human body since they contain a very high amount of starch as compared to potatoes or sweet potatoes, as well as its flour, which is highly recommended for baby food (Tumuhimbise *et al*., 2009). Taro flour is highly recommended to manufacture canned baby foods, through that it is suitable for baby formula due to its starch that is easily digestible also providing help with digestive problems as well as supplementary iron (Joubert and Allemann, 1998; Onwueme, 1999; Shange, 2004; Sibiya, 2015).

According to Salunkhe and Kadam (1998), and Mare (2006) reported that in Africa and Asia, taro is regarded as one of the most crucial tuber crops being grown. Taro corms can be eaten baked, roasted, or fried; however, mature corms and young shoots are normally being used as boiled vegetables (Lewu *et al*., 2009). Boiled corms are normally being smashed and used as a weaning diet (Sibiya, 2015). The eddoe type of taro is known for producing corms with good content of fibre and carbohydrates that are very good at helping people to eliminate digestive problems (FAO, 1992; FAO, 1998; Sibiya, 2015). Taro has been reported to provide several other benefits, including lowering cholesterol levels, reducing insulin requirement, slowing the absorption of glucose, and reducing the chances of getting colorectal cancer (Wilbert, 1986).

However, taro is very much used for medicinal purposes where corms are being used as an abortifacient and also used to treat tuberculous ulcers, fungal abscesses in animals (Paul and Bari, 2011). As compared to the other ten root and tuber crops, taro is regarded as one of the crops containing a good source of dietary fibre (Sibiya, 2015). Proper levels of dietary fibre in food are known to provide excellent benefits such as properly controlling intestinal transit as well as improving and increasing dietary bulk (Wilbert, 1986).

2.2 Agronomy

2.2.1 Environmental requirements

2.2.1.1 Aerial environment

Taro can be grown under tropical, sub-tropical, as well as in temperate area conditions that have long frost-free periods (Westhuyzen, 1967; Purseglove, 1972). It can be grown under ideal temperatures that range from 21°C to 27°C (Shange, 2004). However, high temperatures above 29°C are regarded as very harmful to root growth, but temperatures as high as 36 to 38°C they completely inhibit root growth, such that root growth fails to grow beyond 2 cm (Pardales *et al*., 1982; Shange, 2004). Taro production requires a well-distributed summer rainfall of 1500 mm or more with high humidity to achieve optimum crop growth and yield throughout the growing season (Tindall, 1983). However, an annual rainfall that is more than 2500 mm per annum, together with fertile organic soils, proves to be the best and desirable for the cultivation of taro (De la Pena, 1983; Tindall, 1983; Shange, 2004). The eddoe type is recommended as the species that can tolerate worse environmental conditions as compared to dasheen type. The eddoe type species have been classified as more tolerant to lower temperatures, lower soil moisture conditions, and lower humidity levels as compared to dasheen type species (De la Pena, 1983; Tindall, 1983; Shange, 2004). But dasheen species have been reported performing well when grown under flooded conditions; however, they can be grown under non-flooded conditions (Onwueme, 1978).

2.2.1.2 Soil environment

Taro produces optimum yield when grown under favourable environmental conditions and more critical is the state of the soil, it must be well fertilised and have good drainage for proper crop growth (Mare, 2009). Taro is grown under different types of soil, namely; clay loams, sandy loam, as well as light volcanic soils (Onwueme, 1999; Shange, 2004). A soil that contains a high-water holding capacity with rich organic matter is considered ideal for growing taro as it is of high-quality yield (Sibiya, 2015). Taro requires a well-drained sandy loam to loam soils characterised by high organic content for proper crop growth. However, optimum soil pH is necessary for proper plant growth, and that soil pH ranges between 5.5 to 6.5 a slightly acidic soil with good clay content is considered best (Tindall, 1983; O'Hair and Asokan, 1986; Sibiya, 2015).

Moist soils are better recommended and desirable to improve plant growth for taro, as well as the yield. However, moisture stress should be kept at a minimum as it imposes a threat to the plant growth of taro, whereas, during the dry season, additional irrigation is required to improve growth (Sibiya, 2015). The eddoe type requires more of the soil with good drainage for optimum growth and yield. On the other hand, taro is best recommended for soils characterised as heavy with high moisture holding capacity and under waterlogged soil conditions (Sibiya, 2015). Smith (2006), classified taro as little salt tolerant able to withstand flooding and salinity problems, and it also can be cultivated in low lying areas.

2.2.2 Crop protection

2.2.2.1 Weed Control

Weeds are typically found in growing conditions containing more peat soils, and they are not desirable for crops since they compete for space, light, moisture and nutrients (Andriesse, 1988). However, weeds serve ashosts for pathogens, insects and nematodes (Moody and Ezamuh, 1974). An effective weed control strategy involves a combination of pre-emergence and post-emergence herbicides, and also the preparation of the land is best recommended, especially for major tropical root and tuber crops (Shange, 2004). The negative impact caused by weeds is the reduction of yield and quality of crops. Methods used to control weeds for taro is by having high plant densities and through mulching (Fatuesi *et al.*, 1991). It is highly recommended to practise weeding for taro plots, especially during the first 3 to 4 months after planting for clean cultivation as it is essential during the initial stages of growth with the leaf canopy having a sparse structure (Shange, 2004). Weeds are also experienced during late in the season when the canopy has become open through older leaf senescence (Onwueme, 1978).

Therefore, weed control is regarded as critical for taro during early vegetative growth as well as during the stage where the accumulation of starch and maturation is taking place (Onwueme, 1978). Other methods used to control weed include the use of mechanically or herbicides, especially in the regions where weather conditions are more temperate (Andriesse, 1988). Shallow mechanical weeding is better recommended for dryland taro in order to avoid damaging shallow taro roots (Shange, 2004). While in wetlands, weed control can be practised through maintaining the water level above the soil level (De la Pena, 1983). However, in some countries, manual removal is still being practised because some crops may be too dense in such that machinery and herbicides cannot be used as they may influence on crop quality (Moody and Ezamuh, 1974). Reported in Hawaii, the use of nitrofen chemical has been approved for taro weed control (De la Pena, 1975). The negative impact imposed by modern weed killers is that some are not environmentally friendly, causing more problems to the environment and killing other important species. Several herbicides such as trifluralin and prometryne have been recommended for upland and low cultivation of taro (Onwueme, 1978). However, taro is believed to be sensitive to the spraying of some herbicides (Shange, 2004). It is recommended that thickening agents and spray application be made during the windless morning hours for safety measures (De la Pena, 1983).

2.2.2.2 Pest and diseases control

A study by Deo *et al*. (2009) revealed that pest and disease outbreak is a significant factor contributing to the limited taro production in many countries; thus, taro has been mainly replaced by crops such as sweet potato and cassava. However, improving pest and disease control and genetic engineering could mitigate their spread. Viruses have been classified as dangerous pathogens containing unfavourable infections that could result in a negative impact causing severe yield reductions and death in extreme situations (Sibiya, 2015). Virus infection is subjected to severe yield losses, approximately 20% of yield loss Sibiya (2015), where the infection further infects the main part of the plant.

In recent years some of the major viruses causing severe damage in taro plants have been studied and revealed, namely, dasheen mosaic (DsMV); taro bacilliform (TaBV) and *Colocasia* Bobone disease (CBDV) (Andriesse, 1988). Dasheen mosaic virus (DsMV) is characterised as a potyvirus with flexuous, rod-shaped structures, with the ability to infect both the edible and ornamental aroids, which are mostly spread by aphids. This type of disease has been associated with decreasing yield of taro and also characterised by chlorotic, feathery mosaic patterns on the leaf, distortion of leaves and stunted plant growth (Deo *et al*., 2009). Taro bacilliform virus

(TaBV) is one of the viruses with its infection TaBV, causing the inhibition, mosaic as well as the down curling of the leaf blades in taro (Sibiay, 2015). Furthermore, mixed-infection of TaBV and CBDV is associated with the lethal alomae disease. *Colocasia* Bobone disease virus (CBDV) is another virus resulting in severe yield loss of taro, and it is characterised as a cytorhabdovirus (Andriesse, 1988). It is associated with causing Bobone disease, which initiates by producing a feathery mosaic symptom on the leaves and further cause lamina and veins to be thick, with the young leaves becoming crinkled and leaves will unfurl abnormally, resulting in the petiole becoming shorter with irregular outgrowth (Deo *et al*., 2009).

Soil-borne diseases and pests have also been studied in the past by Andriesse (1998), as a major threat to taro economical yield. Several methods to control soil-borne disease and pests have been implemented, wherein the Netherlands fumigation and sterilisation is used through gasses or steaming within the intensive systems of horticultural cropping including vegetables, pot plants and flowers (Andriesse, 1998). However, these methods are associated with high costs, and they also bring a negative impact on the environment. Whereby the process of steaming and some fumigants such as dichloropropene, methyl bromide, methyl isothiocyanate, and chloropicrin destroy a large proportion of the soil micro-organisms responsible for supplying available nitrogen to the plant. However, there are methods that are fair to the environment that can be used such as, crop rotation, including a clean fallow is regarded as effective against soil-borne pests like nematodes (Deo *et al*., 2009; Sibiya, 2015).

2.2.3 Harvesting and stages of utilisation

The taro usually leaves turn yellow towards harvesting stages, with the petioles getting shortened in the stages of maturity (De la Pena, 1983; Shange, 2004). The main corms then become visible as they push above the soil to indicate they are ready to be harvested (De la Pena, 1983). Taro planted in the dryland and wetland (flooded) is harvested at different stages of maturity, from planting to harvest. The period from planting to harvest between dryland and flooded taro is mainly influenced by environmental conditions, where for dryland, it takes approximately 5-12 months and while it takes about 12-15 months for flooded taro (Onwueme, 1999). Harvesting also depends more on the type of cultivar as well as prevailing weather conditions during the growing season. However, changes in plant structure, such as a decline in plant height and yellowing of the leaves, have been revealed as a signal of maturity for dryland taro to be ready for harvest (Onwueme, 1999). In flooded taro, the same signals occur as well, but they are less similar compared to dryland taro.

Harvesting of taro differs from many countries; some use hand tools in which the commonly used method of harvesting taro is to avoid damaging the corms (Onwueme, 1999). However, nowadays, taro is harvested mechanically to cut cost and time during harvest. The process of harvesting involves pulling the corm up by grabbing the base of the petioles, where the soil around the corm is loosened. Harvesting for flooded taro is relatively slow compared to dryland, through the need to sever the living roots that still anchor the corm to the soil (Onwueme, 1999). For commercialized taro where they prioritized mechanised systems, the harvesting process is still customarily done using hand tools that contribute to the increased labour cost of production.

There are many ways to prepare corms of taro that can be eaten after boiling, baked, roasted, and perhaps fried where they could be consumed together with fish, etc. In several countries known for producing large quantities of taro, the leaves are consumed as food by humans because of the high nutrition and protein, where they are usually boiled and mixed with other foods for a divine taste (Mare, 2006). However, taro has also been used to make chips for human consumption even though their availability is still in small quantities (Shange, 2004). In Hawaii, they have made an effort to produce silage for livestock using taro peels and waste to feed livestock, and also using the large quantities of taro tops mainly left during the process of harvesting the crop (Shange, 2004).

2.3 Nutrition and health

2.3.1 Dry matter content

Numerous studies have attempted to explain the effect of different management practises and environmental conditions on specific gravity, dry matter as well as nutritional composition of root crops (Mohamed, 1985; Long *et al.*, 2004; Casa *et al.*, 2005; Haase *et al.*, 2007; Huang *et al.*, 2007; Kumar *et al.*, 2007; El-Sirafy *et al.*, 2008). Recent evidence suggests that planting date, fertilisation, cultivar including environmental conditions as most critical factors that influence corm or tuber quality (Mare, 2009). However, the landrace plays a vital in determining the response to planting date. Dry matter content is the material remaining after removal of water from a taro corm, normally after being oven dried. Smith (1987) and

Bakayoko *et al*. (2009) emphasized on temperature and water stress having more influence in reducing dry-matter content within the tuber and root crops. Planting date is also another factor influencing dry matter content.

According to Hunter (1998), high dry matter content is the indication of high nutrient content present within tuber and root crops, which also plays a vital role in determining the texture of the plant. In previous studies, they have found that dry matter content has a highly positive correlated relationship with starch content (Cervantes-Flores *et al*., 2011). A study carried in India indicated that sweet potato planted in June, July, and August had a significant lower dry-matter content as compared to those planted in September and October (Mittra and George, 2000). This was attributed to high dry matter accumulation, especially within the leaves and vines in plants grown where temperature periods were very high (June, July, and August). However, a study by Colla *et al*. (2005) revealed similar observations for the potatoes that were planted in 2003, showing lower dry matter content as compared to those planted in 2004. This was due to very high temperatures, especially the night temperature that had influenced and reduced the rate of photosynthesis while increasing the rate of respiratory loss (Mare, 2009). Hammer *et al*. (2007) also observed that cassava storage roots had the highest dry matter during the cooler months while canopy vigour was lowest. Approximately 80% to 90% of sweet potato storage root dry matter is composed of carbohydrates, mainly starch (60% to 70% of dry matter) and sugars (15% to 20% of dry matter with a wide range from (5% to 40% of dry matter), and a relatively smaller amount of pectins, hemicelluloses and cellulose (Woolfe, 1992; Tumwegamire *et al*., 2011).

Dry matter content for taro varies from part to part of the plant. Findings revealed that during the early growing season, approximately 82 DAP, the plant tends to allocate more of the total dry matter percentage to the leaf blades and petioles, and that accounted for about 40% of the total dry matter (Goenaga, 1995; Fa'amatuainu and Amosa, 2016). However, during later stages of growth from 100 to 350 DAP, there was a change in the physical composition of the plant, where the corm and suckers started to accumulate a greater percentage of the total dry matter while the leaf blades and petioles decreased significantly in total dry matter (Fa'amatuainu and Amosa, 2016). During the last three months of plant growth, the corm and suckers are known to high accumulation of dry matter. The growth of the aboveground, such as leaf blades and petioles are characterised with higher biomass during the first three months after planting, and that resulting in greater dry matter in the aboveground parts of the taro plant than the parts below the plant (Fa'amatuainu and Amosa, 2016).

2.3.2 Starch content

According to Ahmed and Khan (2013), starch is considered a carbohydrate with a large number of glucose units combined with glycosidic bonds. Regularly all the green plants produce this polysaccharide in the form of storing energy. However, it is present in large amounts in many staple foods including cassava, wheat, potatoes, and maize (corn), it is also regarded as one of the most common carbohydrates within human diet (Ahmed and Khan, 2013). The dry matter within tuber root crops differs; in different varieties of sweet potato, it has been reported that the dry matter varies from 22 to 45% with the more significant portion allocated to carbohydrate (Byju and George, 2005). Taro has been reported to contain approximately (70-80 g/100g dry taro) starch with small granules that are easily digestible through its small size starch granules **(**Quach *et al*., 2001; Ahmed and Khan, 2013). The starch content of tuber and root crops is influenced by different environmental factors, as mentioned, including very high day temperatures that result in a decreased rate of photosynthesis and an increase in respiration rate while reducing the level of starch content (Mare, 2009). Most of the starch content within the root and tuber crops, which is found within the stem, usually is converted into sucrose influencing an increase in sugar levels, while the dry matter decreases (Debon and Tester, 2000). The effect of high and uneven air temperature that may contain water stress causes abnormal growth and the bulking rate of tuber crops (Smith, 1987). Temperature plays a vital role in the uptake and metabolism of mineral nutrients within plants through speeding up the transpiration rate (Kader and Rolle, 2004; Mare, 2009).

2.3.3 Protein

2.3.3.1 Minerals and vitamins

The composition of minerals and vitamins in taro differs throughout the parts of the plant. The genotype, age of the plant, environmental conditions as well as the interaction between the genotype and the environment are one of the factors contributing to the variation of nutritional composition in taro corms (Wills *et al*., 1983; Mwenye *et al*., 2011; Mergedus *et al*., 2015). The total composition of proteins and minerals levels in taro is considered as vital since they play a major role as the components of the human diet (Mare, 2009). Previous studies investigating mineral compositions of taro corms have indicated potassium as one of the minerals that are present in large quantities (Mergedus *et al*., 2015). However, minerals such as calcium, magnesium, and phosphorus have been found to be abundant minerals present within taro corms (Bradbury & Holloway, 1988; Huang *et al*., 2007; Lewu *et al*., 2010; Mwenye *et al*., 2011). Some studies have also indicated that significant amounts of zinc are present in taro (Mergedus *et al*., 2015). Based on nutritional observation, iron and manganese are reported to be present in low quantities in taro corms (Lewu *et al*., 2010; Mwenye *et al*., 2011).

In the major tuber and root crops, only cassava does not contain groups of storage proteins; nevertheless, these vary in their biological properties and evolutionary relationship (Shewry, 2003). Taro is relatively different from other tuber and root crops through that it contains two major types of storage protein, and which are mannose-binding lectin as well as trypsin inhibitor to sporamin (Shewry, 2003). High temperatures, especially when frying taro in oil is prone to collapsing the calcium oxalate containing cells (raphides), resulting in the breakdown of oxalate structure (Mare, 2009). However, the mechanism of involving oxalate reduction through high temperatures (heat) has not been properly and fully explained (Ndimantang *et al*., 2006).

Taro roots are known to contain precious organic compounds, minerals, and vitamins that are considered vital for the human diet (Kaushal, 2015). Taro root composed of the essential amount of dietary fibre and carbohydrates, including high levels of vitamin A, C, E, B, and folate as well as iron, phosphorus, magnesium, zinc, copper, potassium, and manganese (Kaushal, 2015). According to Kita (2002), the starch content of the potato tubers is not the only component influencing the crisp texture; other components include protein and nitrogen also influence the quality of crisps. The mineral composition is known to determining the colour of taro chips through influencing, reducing sugar content (Mare, 2009). However, the production colour of the taro fried chips is also more influenced by amino acids together with sugars, including tuber proteins (Mare, 2009). Some studies by Roe *et al*. (1990) reported that approximately 8% of the structural change in colour of crisps is mainly influenced by amino acids. Taro varieties and the nature of taro corms are considered as key factors that determine the success of making taro chips (Bradbury and Nixon, 1998; Hollyer *et al*., 2000; Mare, 2009).

2.4 Water and health nexus

2.4.1 Nutritional water productivity

Nutritional water productivity (NWP) is defined as a measure of yield and nutrition yield per unit water used, and it is considered suitable and applicable for sustainable food production given the limited water resources as well as modified diets (Renault and Wallender, 2000; Stockholm International Water Institute (SIWI), 2004; Chibarabada *et al*., 2017). According to Mabhaudhi *et al.* (2016), NWP is a tool that is designed to address accessibility, availability, as well as utilisation components of food security. NWP has been discovered as a useful tool in terms of linking water, agriculture, and nutrition through addressing the impacts caused by agriculture with regards to food and nutrition security (Chibarabada *et al*., 2017). However, linking NWP with health indicators could be proven more useful in keeping the water-food-nutrition-health nexus functional and reducing nutrition problems in many parts of the world (Mabhaudhi *et al.*, 2016). Sub-Saharan African (SSA) countries have been perceived as more vulnerable to hunger and malnutrition all over the world (Food and Agriculture Organization of the United Nations (FAO), 2017). Therefore, the act of adopting and implementing the water food-nutrition-health nexus as the action of planning and improving the state of rural development and food as well as nutrition security programmes could be associated with positive results, especially for SSA.

The nutritional productivity of water is calculated with respect to energy, calcium, fat, vitamin A, and iron output per unit water input (Renault and Wallender, 2000). Water use efficiency (WUE) and water productivity (WP) are newly designed tools used nowadays to evaluate the effect of improving and increasing food production, especially under water scarcity regions, of which more are found in SSA (Stanhill, 1986; Descheemaeker *et al*., 2013). NWP is expected to be a more useful tool especially within the area of semi and arid tropics which is South Asia and SSA, where the issues of water scarcity and nutrition insecurities continue to rise on a daily basis (Mabhaudhi *et al*., 2016; Chibarabada *et al*., 2017). Water has been identified among scarce and limiting natural resource factors especially for increasing food and fiber production that could provide a rising number of the world population that is also competing with other water users' sectors such as, industries, municipality, environment, etc. (Renault and Wallender, 2000).

Water plays an essential role in achieving food and nutrition security, especially for improved food nutrition as well as human health, and that cannot be neglected. Receiving enough and quality water is regarded as life threatening, mostly for agricultural production and improving food and nutrition security. Recently, yields within the SSA regions have been recorded very low compared to the yields in the USA and Europe, where they are approximately 200% to 300% higher (Mabhaudhi *et al*., 2016). Previous studies have suggested that this considerable yield gap is more aggravated by the lack and poor agronomic practices arising in the SSA, as well as the lack of using improved crop varieties (Mabhaudhi *et al*., 2016). Therefore, the newly formed index, which is NWP, is considered as the starting point and an appropriate index for evaluating the impact of water use together with agriculture towards food and nutrition security around the world (Mabhaudhi *et al*., 2016). Most of the poor rural farmers in SSA are struggling to afford inputs that can increase their productivity, namely; herbicides and chemicals (Druilhe and Barreiro-Hurlé, 2012).

In terms of sectors that use the most water, the agricultural sector has been identified in the global reports as the biggest water user, using approximately 60% to 90% of freshwater withdrawals (Renault and Wallender, 2000; UN, 2006). It is predicted that water resources will impose a severe threat on global agriculture, but the SSA region is regarded as more vulnerable with increasing climate change resulting in low rainfall with a rapid increase in population (Rijsberman, 2006). Reviewed climate change report suggests that severe impacts changes caused by climate change within the SSA will negatively impact more in water availability as well as rainfall resulting in decreased agricultural productivity (Pachauri, 2014; Mabhaudhi *et al*., 2016).

Agricultural scientists have invested a lot of knowledge in recent years by developing new water-saving methods that will fit recent changes in climate change (Molden *et al*., 2003; Wenhold *et al*., 2012). Scientists specializing in irrigation systems have been working tirelessly to improve and design irrigation systems that are more efficient, while breeders are also trying to breed and improve crops that are water use efficiency and crop scientist continue to develop cropping system that is water-saving together with better field management practises (Mabhaudhi *et al*., 2016). However, these improvements in water productivity have been considered as very useful, but the problem has not been solved since water scarcity is not the only issue facing the world. The major problem is producing and supplying enough food to the world that has adequate nutrients required by a human body. Statistics have indicated that almost 30% to 40% of the world population is suffering from undernutrition, micronutrient deficiency, and in recent reports, it has been confirmed that the number of people getting obese or overweight is increasing rapidly (Rosegrant *et al.*, 2014).

Current studies have indicated that malnutrition is considered as a significant issue facing the world, but the SSA region is regarded as most affected (OWGGASDG, 2014; Mabhaudhi *et al.*, 2016). The proposition by United Nations of Sustainable Development Goal 2 (SDG) focuses more on "ending hunger, achieve food security and improved nutrition and ensure sustainable food production by 2030", however, this approach is not covering the whole scope which is achieving food security that is high on nutrition (Mabhaudhi *et al.*, 2016). At the same time, the water productivity approach is more focused on dry matter production and not considering the nutritional content of the biomass being produced. This approach is more focused on "more crop per drop," which is increasing food production while ignoring the main goal of improving the nutritional content of the food. Mabhaudhi *et al.* (2016) believe that putting more efforts through improving food production and nutrition security will likely result in a good state of physical and economic access to adequate food especially for the poor.

2.4.2 Implications for crop management

Crop management is a process starting from the sowing of the seed, followed by crop maintenance during the phase of growth and development, ending with crop harvest, storage, and distribution process (Madsen, 1995). Crop management is much known to influence pests together with their natural enemies within the soil environment (Rusch *et al.*, 2010). Crop management activities causechanges to the soil environment, and as a result, end up influencing microbial growth as well as biodegradation process that alter plant residues and applied pesticides in the soil (Mandelbaum *et al.*, 2008). Crop management activities such as taking good care of the soil are one of the essential components to make sure the adequate nutrients are available for proper plant growth, which could result in optimum yield (Madsen, 1995).

However, taro is reported doing well under good crop management, such as favourable environmental conditions with well-fertilized soil and good drainage to allow healthy plant growth (Onwueme, 1999; Shange, 2004). Taro performs well under different soils, which include clay loams, sandy loam and light volcanic soils (Onwueme, 1999; Shange, 2004). The type of fertiliser to choose when cultivating taro is critical, applying the right amount and knowing the perfect timing and the method to apply fertiliser is also important to assure optimum quality yields (Madsen, 1995). Poultry manure is considered very effective organic fertiliser for taro, contributing to the vital source of plant nutrients resulting in producing higher yields (Ansah, 2017). In order to understand different methods of applying fertiliser especially for taro crop, several factors need to be in consideration that includes the type, and nature of fertiliser, understanding soil conditions, crop type as well as weather conditions. In Ghana, it has been reported that tuber and root crops, as well as other crops, are most affected by a decline in soil fertility, and that is characterised as one of the limiting factors to crop production (Ansah, 2017). However, it is essential to improve the soil by adding a soil amendment, especially for continuous land cultivation in order to enhance soil physicality and chemical properties and avoid the soil to lose essential plant nutrients. In many parts of the West African sub-region where soil amendments have not been applied, there is a decline, especially on the yield of taro as well as plant growth (Ogbonna and Nweze, 2012; Ansah, 2017).

2.4.3 Implications for food security

Food security refers to the availability of adequate and nutritious basic food that could supply the world in order to sustain a steady expansion of food consumption as well as to offset production and price differentiation (UN, 2006). Food security is considered achieved when individual households always have means and capacity to access adequate nutritious food, in the form of self-production or either through purchasing from the market (FAO, 1998; Bourke *et al.*, 2001). In the modern era, food security has improved by a little within some countries in the African Continent as compared to the olden days. This is supported by a relatively higher proportion of the population that practises more of subsistence agricultural farming, contributed by having rights to access land mainly for food production contributing further to try and improve the state of food security within the continent (Bourke *et al*., 2001). However, there is a variety of subsistence food sources and where most people, especially in the rural areas, have access to cash income like in SA the grant money, which they use to buy food during the season where subsistence food supplies are not enough to supply food for all (Bourke, 2001).

Two major factors contributing to changes in subsistence agricultural systems are, the ability to adopt new staple crops as well as having access to cash income, and they have been studied as factors that contributed to the improved state of food security to date especially within the

African continent (Bourke, 2001). The majority of the village people that are engaged in subsistence farming are now able to use cash to buy food, especially during periods when subsistence crops fail to produce food (Bourke *et al*., 2001). Cash income is mostly spent on food items such as vegetable oil, rice, flour, and animal fat. More benefits have been achieved through using cash to buy food, especially when there is inadequate subsistence food supply, where death rate and trauma have been reportedly reduced during food time shortages (Malau, 2001). As a result, having access to cash is essential as it provides a positive relationship in improving the state of food security for most South Africans, especially the ones in rural areas. There is a greater need for food security to better the state of cash income, especially for the poor people, mainly found in the Sub-Saharan Countries than those of the middle-income or high-income earners (Bourke, 2001).

As mentioned, the agricultural sector uses approximately 70% of the world's total water withdrawals, making it the greatest water user than any other sector worldwide (UN, 2006). Not only have diseases imposed a threat to food security, but also water deficit is another factor increasing food insecurity and starvation around the world (Johnson *et al*., 2001). Water deficit has been affecting the production of cereal and making it difficult for developing countries to afford cereal products (Yang *et al*., 2002). The lack of water resources has resulted in limited local food production, which has increased food insecurity, forcing especially Asia and African countries to import cereal grains to compensate for the loss of food production (Cosgrove and Rijsberman 2000; Smith *et al*., 2000). Taro as the crop that uses more water, its production is also affected by water deficit. The challenge faced is increasing and commercializing taro production worldwide. Increasing taro productivity and minimizing post-harvest losses to rot could be essential to improve its demand for food, which could result in improved food security, especially for developing countries (Oneh, 2013).

Food security has been more affected by crop diseases, and the threat continues. However, crop diseases have been reported to affect the world agricultural productivity resulting in a reduction of more than 10%, which is close to half a billion tonnes loss of food every year (Hunter and Iosefa, 1993; Singh *et al*., 2012). These diseases are associated with reducing food availability, especially for the poor, also resulting in increased food prices as well as imposing a serious threat to rural families and regional food security. Other factors contributing to food insecurity are drought, cycles in planting rate, and very high periods of rainfall (Bourke, 1990). Food shortages have imposed a threat to human life, especially during the period of 1941 and 1997 through drought and frost, contributing to an increased in the death rate (Bourke, 1990). Future food security could be impacted by a different number of factors including, land degradation, excessive soil moisture, large variation in planting rates and human diseases. However, future food security could be improved through improving technology for food production, mainly in places where people depend on taro for survival as a staple crop. The focus should be mainly on vulnerable environmental conditions for improved food production technology.

Food security could also be improved by improving transport routes, which will create better access to food markets, and for this to be accomplished, roads always need to be maintained and kept into good conditions together with bridges including other transport infrastructure to allow for easy access of food to the markets (Malau, 2001). Better access to the markets could be achieved through improving marketing, mainly for cash crops. Future food security could also be improved by increasing prices for cash crops, especially for the domestic and export market (Kokoa, 2001). However, there is still a challenge in improving future food security, factors contributing to that are HIV/AIDS epidemic, and global climatic change (Malau, 2001). However, many changes can be made that will yield a positive result in trying to improve food security and reduce the percentage of hunger, particularly for the poor. One of the things that can be done to improve the state of food security is by increasing cash income and try to come up with ways to improve subsistence food production, mainly for the poorest people (Kokoa, 2001). These changes possible will not just yield a positive result for the South Africans, but other African countries trading with SA could also benefit.

SA government should make it their priority to improve domestic food production and make it one of their vital policy target implementations. However, for this to be achievable, the government should put more focus on crops that perform very well, and which are known to produce good returns, especially crops such as taro, sweet potato and other root crops (Kokoa, 2001). Studies have indicated that there are very high chances of failure, especially for marketing, agronomic and economic reasons when it comes to the attempts of producing wheat, rice, maize, grain legumes and sorghum (Malau, 2001**)**. The increasing diversity of cash income sources with the idea of minimizing poverty will result in many positive implications and not only to better the food security, especially for rural and urban SA people (Kokoa, 2001**)**. The list goes on, such as improving access to education for all, better access to health as well as easy access to information.

SA is considered a food-secure nation; however, not every household has access to nutritious and adequate food and that is still an issue for many other African countries (Jacobs, 2010). One of the contributing factors to households not having access to nutritious food is the rising of food prices, which affect food security resulting in poor households suffering the most (Mkhawani *et al*., 2016). In a report that was compiled by the World Bank, during 2010-2011, food price increases have resulted in approximately 44 million people suffering from poverty (Mkhawani *et al.,* 2016). Further a survey performed in 2012 by the South African National Health and Nutrition Examination indicated that approximately 31% of the households in the Limpopo province are still suffering from hunger and 27% of the population predicted to be at risk (Shisana *et al*., 2014). However, in most cases chronically urban and rural poor, the landless and female-headed households are the most affected ones due to this rising of food prices in this country (Mkhawani *et al*., 2016).

Nevertheless, taro contribution towards food security over centuries, even during the times before the arrival of commercial crops originating in Europe, which nowadays prevail traditional agriculture such as potatoes but in SA agronomic research into taro has been considered as very recent (Mare, 2006; Modi, 2003; 2007; Shange, 2004; Mare, 2009). There are some other aspects that have not been fully studied when it comes to SA taro, which includes the relationship within agronomy and quality yield of the crop as compared to other root crops such as potato (Mare, 2009).

2.5 Conclusion

Taro is classified as an important edible aroid root crop for many countries in the Pacific and in the African region. Taro production in SA is mainly practised by smallholder farmers to the coastal areas of KZN and in the Eastern Cape with some limited inland and upland production being practised in Mpumalanga. Taro being considered as a vital subsistence commercialised crop; however, previous studies have indicated that the existing gap of science knowledge research is one affecting its production in SA. The review suggests that there is still a scant of knowledge of water use and water productivity of local taro landraces with regards to yield quality. Thus, water nutritional productivity is an important new aspect being introduced specially to root and tuber crops contributing to achieving food security as a form of improving human life. There is still more that needs to be done when it comes to water use, in order to better advise farmers to improve their yields and the quality of their crops. Farmers need to be aware of the management practices that need to be followed when cultivating taro, such as planting date, fertiliser, cultivar, soil type, and weather conditions. It was clearly indicated from the review that planting date and fertiliser play an important role in determining the quality of taro yield. Furthermore, the lack of knowledge and understanding of taro diseases is one of the factors affecting more yield production as well as physiological determinants that may limit growth and development in SA.

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CHAPTER 3

GROWTH RESPONSE OF TARO LANDRACE TO DIFFERENT IRRIGATION TREATMENTS UNDER CONTROLLED ENVIRONMENT FACILITY

3.1 Summary

Taro (*Colocasia esculenta* L. Schott) is mainly distributed within the tropics and subtropics and regarded as the vital root crop of the Araceae family (Lebot, 2009; Mabhaudhi, 2012). Taro is considered to be one of the oldest crops known to man with an estimated dated history of about 10 000 years (Rao *et al*., 2010). Taro production is mainly distributed from the coastal areas of KwaZulu-Natal and Eastern Cape provinces, where farmers primarily rely on landraces as planting material for taro cultivation (Shange, 2004). However, in South Africa, taro remains one of the underutilised crops due to lack of scientific information (Mabhaudhi, 2012). Uyeda *et al*. (2011), has reported that taro has low levels of utilisation due to being highly perceived as one of the least water-efficient crops. The results also supported by that the information describing water-use of taro as well as possible drought tolerance is minimal.

South Africa is classified as a water-scarce country; hence water availability is still considered as a significant limiting factor to crop production, and that also threatens household food security (Bennie and Hensley, 2001; Mabhaudhi, 2012). Further stated by Petit *et al*. (1999) and Hassan (2006), that in the near future, water scarcity will put crop production and food security at higher risk by threatening food supply to the growing population, especially in the developing countries. There are currently minimal literature reports which were conducted on the information describing drought tolerance and water use of taro (Sivan, 1995; Sahoo *et al*., 2006; Uyeda *et al*., 2011). Growth parameters such as stomatal conductance, leaf area, and leaf number were studied on drought tolerance in two dasheen, and eddoe taro varieties including tannia (*Xanthosoma sagittifolium*) and these parameters were all observed with a decrease in response of water stress (Sivan, 1995; Mabhaudhi, 2012).

Agricultural production is in severe risk within the Sub-Saharan Africa and South Asia regions because of a high increase in the level of drought and water scarcity (Falkenmark *et al*., 1989; Seckler *et al*., 1999; Rijsberman, 2006). In recent years till to date metrics such as water use efficiency (WUE), water productivity (WP) and nutritional water productivity (NWP) have been recommended as useful tools to increase food production especially in the regions that

are classified water-scarce in the semi- and arid tropics mainly South Asia and sub-Saharan Africa where they are still experiencing high levels of water scarcity and food nutrition insecurity (Mabhaudhi *et al*., 2016; Chibarabada *et al*., 2017). NWP is defined as a measure of yield and nutrition outcome per unit of water consumed and is very effective under limited water conditions for sustainable food production (Renault and Wallender, 2000; Mabhaudhi, 2012). However, better agronomic practices, improved irrigation management, and growing appropriate crops using proper genotypes need to be well mastered when using WP tool in regions characterised as water-scarce (Passioura, 2006; Molden *et al*., 2010; Karrou and Oweis, 2012; Descheemaeker *et al*., 2013; Estrada *et al*., 2015). These metrics have achieved similar results; thus, for future purposes, there is a need to be merged to highlight the existing challenges of producing more nutritious food using less water per output (Chibarabada, 2018).

Environmental conditions are changing due to current weather conditions that have driven a need to develop information that will evaluate responses of local taro landraces to water stress to determine their water use mechanism under different irrigation treatments. Such information could prove to be pivotal to smallholder farmers who have no access to irrigation but with limited rainfall in assisting them with better cultivation techniques for drought-tolerant crops such as taro. It was hypothesised that there is no statistically significant difference between the levels of starch present at 30% compared to 100% ETa crop water requirement. The selection of two water treatments was based on a study done by Sibiya (2015). The study objective was to determine the effect of different water levels on growth, development, yield, WUE, WP, and NWP of a single taro landrace (*Colocasia esculenta L. Schott*) under controlled environmental conditions.

3.2 Material and Methods

3.2.1 Planting material

Local South African taro landrace was collected from smallholder farmers of Ezigeni, at Umbumbulu district (28°55' S, 31°42' E) in the Midlands location of KwaZulu-Natal (KZN), in March 2018. Umbumbulu (UM) landrace is classified as an upland landrace (eddoe type), characterised by a central corm and several side cormels, which are the edible parts and propagated using sprouted corm and head setts (Lebot, 2009; Mabhaudhi, 2012). The eddoe type landrace is generally known to take about six months to mature, however under rainfed conditions. It can be extended even further up to 8 to 10 months depending on the season and the location (Sibiya, 2015).

Figure 3.1: Umbumbulu (UM) taro landrace of KwaZulu-Natal (Sibiya, 2015).

3.2.2 Description of the site

The controlled environment study was conducted in growth tunnels at the University of KwaZulu Natal's Controlled Environment Facility (CEF) in Pietermaritzburg (29°37'S; 30°16'E) during the late summer planting season of 2018. The environmental conditions inside the tunnels were characterised as semi-controlled (~33/18°/C day/night; 60–80% RH). The controlled environment experiment was planted on March 2018.

3.2.3 Experimental design

There were two factors tested in this experiment, that is, landrace and crop water requirement (ETa) where each plant represented a replicate. The two irrigation treatments were 30% and 100% of crop water requirement (ETa). One taro landrace was planted on built-in beds (1 m high) (Fig 3.2) availability of taro landrace was the reason for a single taro landrace to be used in the study. The soil in the beds was taken to the KZN Department of Agriculture and Rural Development Soil Analysis Laboratory for determination of chemical and physical properties (Table 3.2). The experiment was arranged in a randomised complete block design (RCBD), with a planting density of 0.3 m between and 0.6 m within rows (55 556 plants/ha) was used for the experiment.

Figure 3.2*:* Taro landrace (Umbumbulu) planted in a growth tunnel on raised beds under different irrigation regimes (100% and 30% ETc).

3.2.4 Irrigation

Drip irrigation method was adopted to provide daily crop water requirements. The irrigation system used includes a pump, filters, two solenoid valves, two water meters, a control box, netafim inline drippers with four split drippers, and a mainline. The maximum allowable operating pressure of the system was 200 kPa, while the drip rate was running at 33 ml per min with an average discharge rate per dripper of 2 litre per hour. The plant spacing was used for dripper line spacing. Irrigation scheduling was based on monthly average reference evapotranspiration (ET_o) values as well as from crop factor (K_c) (Allen *et al.*, 1998).

The values of reference evapotranspiration (ET_o) were obtained from the UKZN Agrometeorology Discipline's automatic weather station (AWS) that is located on-site, where the AWS calculates ET_o daily according to the FAO Penman–Monteith's method (Allen *et al.*, 1998). Some studies indicated that it takes about seven months (210 days) for taro to be fully matured and ready for harvesting; however, this differs from authors as they believe it mainly depends on growth stages of the crop (Lebot, 2009; Mabhaudhi, 2012). Crop coefficient (Kc) values for taro were described by Fares (2008), whereby K_c(initial) = 0.5 (2 months), K_c(med) = 1.15 (4 months) and K_c(late) = 0.65 (1 month). As described by Allen *et al.* (1998), using the single crop coefficient approach, crop water requirement (ETa) was calculated using the values of Kc and ET_o adapted from the AWS.

$\mathbf{ETa = ET_o * K_c}$ **Equation 3.1**

Where:

ETa = crop water requirement (mm), ET_o = reference evapotranspiration (mm), and K_c = crop factor (Allen *et al*., 1998) (Table 3.1).

All treatments were watered to field capacity before the treatments were imposed. Irrigation was applied three times a day during the mornings (7 am), afternoons (12 pm) and late afternoons (4 pm) to minimise losses due to evaporation and drainage and ensure moisture water availability in the soil during peak periods of the day.

Table 3.1: Crop water requirements of taro landrace grown under a controlled environment.

		ET_o	ETa	Duration	Total water applied
	K_c	mm	mm	Days	mm
Initial	0.50	3.00	1.50	60	90
Mid-season	1.15	3.00	3.45	120	414
Late-season	0.65	4	2.6	141	366.60
Total water applied (100% ETa)					870.60
Total water applied (30% ETa)					222.96

K_c = crop factor based on Allen *et al.* (1998); ET_o = reference evapotranspiration; ET_a = crop water requirement

Values of ETa in mm (depth) were converted to m^3 (volume) using the formula;

Volume (m^3) = Area (m^2) × Depth (m) **Equation 3.2**

3.2.5 Data collection

3.2.5.1 Physiological measurements

Physiological measurements were done weekly before the midday irrigation event (between 11 am and midday). A random sample of four plants from the tunnel beds of each experimental plot was considered to determine the parameters involving emergence, leaf number, plant height, leaf area, chlorophyll content index (CCI), stomatal conductance (SC), soil moisture content (SWC), chlorophyll fluorescence (CF), yield and yield components. Crop growth and development data were collected every week till harvest. Emergence was defined as the protrusion of the shoot through the seed corm, 2 mm above the soil surface (Sibiya, 2015). Emergence was recorded when at least 90% of seedlings have emerged. Leaf number was counted only for fully formed, fully unfolded leaves with at least 50% green leaf area. Plant height was measured from the soil surface up to the base of the second youngest, fully formed and unfolded leaf. Leaf area plant^{-1} (A) was measured using a centimetre ruler, the product of leaf length (L), and leaf Breadth (B).

$$\mathbf{A = L * B\ (cm^2)} \qquad \textbf{Equation 3.3}$$

Where: A = Leaf area plant^{-1} in cm^2, L = leaf length in cm, and B = leaf breadth in cm.

Chlorophyll content index was measured on the adaxial surface of the second youngest fully formed, fully unfolded actively photosynthesizing leaves using a SPAD 502Plus chlorophyll content metre (Konica Minolta, USA). Stomatal conductance was measured during the midday using a steady-state leaf porometer model SC-1 (Decagon Devices, USA); measurements were taken on the abaxial leaf surface of the 2nd youngest fully unfolded leaf (Sivan, 1995). Soil moisture content was measured weekly using ML–3X Theta Probe connected to an HH2 handheld moisture meter (Delta-T Devices, UK). In each plot, three probes were carefully inserted within the root zone at an angle (<90◦) then buried with soil. In order to determine plant photosynthetic efficiency, chlorophyll fluorescence (CF) was measured on the adaxial surface of young, fully expanded, and fully exposed green leaves using a Pocket PEA-Chlorophyll Fluorescence System (Hansatech Instruments, United Kingdom). Before measuring CF, a sample area of the targeted leaf was covered with a lightweight leaf clip (Hansatech Instruments, United Kingdom) for 20 minutes to eliminate light and allow for dark adaptation.

3.2.5.2 Yield and yield components

Taro plants were harvested 92 days after planting for 30% ETa water treatment and 141 days after planting for 100% ETa water treatment. To determine corm/cormel yield and other yield parameters, eight plants were harvested from each experimental plots and yield parameters included, biomass (B), the number of corms per plant, total corm mass per plant, and corm yield (Y) were determined at harvest. Thereafter, harvest index (HI), water use efficiency (WUE), water productivity (WP), and nutritional water productivity (NWP) were determined. Biomass was determined by weighing the shoot together with roots and corms. Corm yield was determined by weighing edible corms, and HI was then calculated as the proportion of Y to B. Plants were carefully dugout to avoid damaging roots. The yield was converted to kg per hectare. Water-use efficiency (WUE) was determined as follows:

WUE = Biomass/ ETa **Equation 3.4**

Where: WUE = water-use efficiency in (kg ha^{-1} mm^{-1}), Biomass = above ground biomass plus below ground portion in (kg·ha^{-1}), and ETa = actual crop evapotranspiration/water use in (mm^{-1}).

3.2.5.3 Determination of water productivity (WP)

Water Productivity (WP) was calculated as:

$WP = Y_a / ETa$ **Equation 3.5**

Where: WP is water productivity (kg m^{-3}), Y_a is the actual yield based on fresh corm yield (kg·ha^{-1}), and ETa is the water applied (m^3·ha^{-1}) based on crop water requirement.

3.2.5.4 Determination of nutritional water productivity (NWP)

Nutritional water productivity (NWP) was calculated based on the formula by Renault and Wallender (2000):

$NWP = (Y_a/ETa) \times NC$ **Equation 3.6**

Where: NWP is the nutritional water productivity (nutrition m^{-3} of water evapotranspiration), Y_a is the actual harvested yield based on fresh corm yield (kg·ha^{-1}), ETa is the water applied based on crop water requirement (m^3·ha^{-1}), and NC is the nutritional content per kg of product (nutrition unit·kg^{-1}).

3.2.5.5 Determination of nutritional content (NC)

To preserve nutrients and avoid further metabolic reactions, freshly harvested taro corms were washed, peeled, rewashed, and sliced into a thickness. Peeled corms were dried at 50◦C for 48 h in a hot air oven Yamato DKN600 mechanical convection oven with forced-air circulation (60 cm × 50 cm × 50 cm internal dimensions; Yamato Scientific America Inc., Santa Clara, CA); after yield determination. Thereafter, dried samples were then milled into flour using a warring blender (Model: 8010S, Torrington, USA) and sieved (screen size: 180 µm) to obtained fine flours and sent to the KZN Department of Agriculture and Rural Development Plant Nutrition Laboratory for analysis. The nutrients analysed per dry matter basis included macro-nutrients, such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), and micro-nutrients including, Boron (B), copper (Cu), iron (Fe), aluminium (Al), manganese (Mn), zinc (Zn), carbon (C) and sodium (Na). Nitrogen was run on a LECO CNS instrument calibrated with an imported sample and checked against known standard samples. The analyses for calcium, magnesium, potassium, sodium, zinc, copper, manganese, iron, phosphorus, and aluminium were done using the I.C.P instrument, which was calibrated on four different levels of imported standards for each of the elements. Internal controls were run every tenth sample, and the instrument was checked regularly using an imported multi-element standard (Naramabuye *et al*., 2008).

3.2.5.6 Determination of starch content

Starch was determined using the enzymatic method of Weinmann (1947) with modifications. Oven-dried, ground material (0.20 g DM) was mixed with 10 ml 80% (v/v) ethanol and homogenized for 60 seconds. Thereafter, the mixture was incubated in a water bath set at 80°C for 60 minutes. The supernatant was suctioned off. These steps were repeated twice then cooled before samples were dried in a Savant Vacuum Concentrator (SpeedVac, Savant, NY, USA). Warm (40 – 50°C) acetate buffer (10 ml) and 200 µl of hexokinase were added to each sample then incubated at 90°C for 30 minutes. Samples were allowed to cool at room temperature before adding 200 µl of G6P-dehydrogenase (G6P-DH) then incubated at 60°C for 20 hrs. Thereafter, samples were vortexed and diluted to 200 ml with distilled water and filtered through Whatman filter paper No. 541. An aliquot (200 µl) of the filtered sample was then taken and diluted further to 3 ml with distilled water. Copper reagent (5 ml) was then added to each sample vortexed, and placed in a boiling water bath for 20 min. Arsenomolybdate (5 ml) was then added to each sample after cooling, vortexed, and left to stand at room temperature for one and a half hours. Samples were diluted (with distilled water) to 200 ml agitated and read at 750 nm.

3.2.6 Agronomic practices

Soil samples were collected from tunnel L2 in brick beds 6 and 8 before planting and submitted for soil fertility and texture analyses to Cedara College. Table 3.2 indicates the soil sample test results prior to planting taken at the Controlled Environment Facility (CEF). The beds were ploughed before planting. Fertilizer was then applied based on the result of soil fertility analyses, where organic fertilizer (Gromor Accelerator®) was applied at a rate of 5 330 kg per hectare recommended by Mare (2010), 133,25 g per planting station calculated based on plant population. (Table 3.3) indicates the nutritional composition of Gromor Accelerator®. Organic fertilizer was first mixed with soil before a single cormel was planted per planting station, while the planting holes were opened using a hand spade. According to Sibiya (2015), propagules should first be treated with bactericide and fungicide (Sporekill®) in the prevention of rotting during sprouting. The tunnel beds were kept weed-free through routine hand weeding when required in the tunnels during the growing season. Karate (30 ml per 15 litres water) was sprayed eight weeks after planting and repeated two times at weekly intervals to control mealybug.

Table 3.2: Physical and chemical characteristics of the soil in the tunnel beds at the Controlled Environment Facility (CEF)

Sites	**P**	**K**	**Ca**	**Mg**	**Zn**	**Mn**	**Cu**	**pH**	**Org . C**	**N**	**Clay**
	…........................... mg. L^{-1}...........................							**(Kcl)**	**…..........% …..........**		
Tunnel Beds	100	296	2413	350	23.5	44	6.4	5.09	3.3	0.32	38

Table 3.3: Nutritional composition of Gromor Accelerator®

N	P	K	Mg	Ca	S	Fe	Cu	Zn	B	Mn	Mo
(g kg^{-1})						(mg kg^{-1})					
30	15	15	5	20	0,6	2000	40	250	40	400	4

3.2.7 Statistical analysis

Data was collected and statistically analysed during the season by using the computer statistical program GenStat® (Version 18, VSN International, UK). Analysis of variance (ANOVA) was employed to test the overall significance of the data, while the least significant difference (LSD) test at $P = 0.05$ was used to compare the differences among treatment means.

3.3 Results

3.3.1 Crop establishment

Results of crop emergence indicated highly significant differences ($P<0.001$) between water treatments (30% and 100% ETa) and time. The interaction between water treatments and time (WAP) was also highly significant ($P<0.001$). However, the effect of taro landrace on crop establishment was not significant ($P>0.05$). Umbumbulu (UM) landrace was slow to emerge at 30% ETa (Figure 3.3) compared to 100% ETa treatment, with zero percent emergence observed for both treatments during the first four weeks after planting. The UM landrace emerged better at 100% than 30% ETa, reaching 100% emergence within 9 WAP at 100% ETa compared to 89% emergence recorded under 30% ETa treatment over the same period (Figure 3.3). The 100% ETa was shown to emerge better with regards to emergence rate and uniformity, compared with the 30% ETa with a decrease of about 25.4% relative to 100% ETa treatment based on mean values.

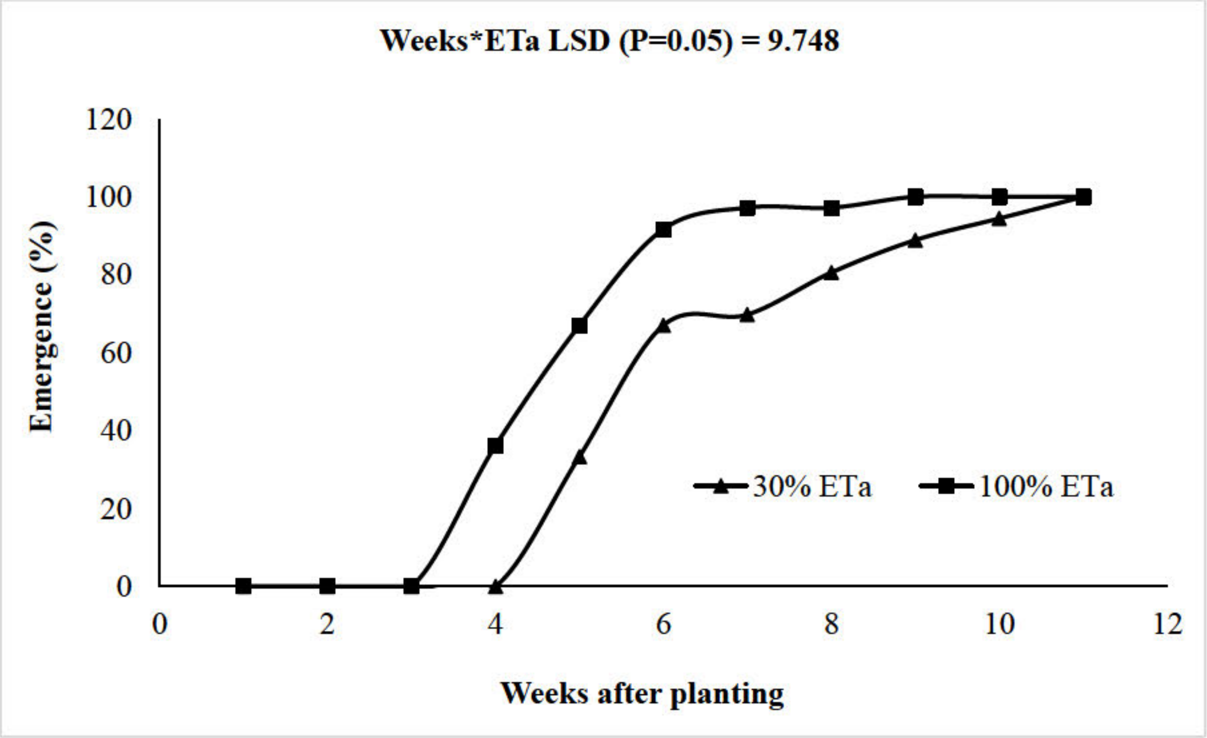

Figure 3.3: Crop establishment of a taro landrace [Umbumbulu (UM)] in response to water treatments (30% and 100% ETa) under controlled environment conditions during the 2018/19season.

3.3.2 Plant height

The results showed significant differences (P<0.001) between the interaction of water treatments and time (WAP) with regards to plant height (Figure 3.4). However, the effect of taro landrace was not significant (P>0.05) with respect to plant height, including other growth parameters in the study. The trend indicated a steady increase in plant height within the first few weeks after planting (5 to 15 WAP) between water treatments 30% and 100% ETa then started to increase over time from 19 WAP observed over the period (Figure 3.3). Based on the mean values of plant height across both water treatments, the 100% ETa had taller plants compared to 30% ETa treatment. The trend results indicated that plant height at 30% ETa decreased by 24.8% relative to the 100% ETa treatment, based on mean values (Figure 3.4).

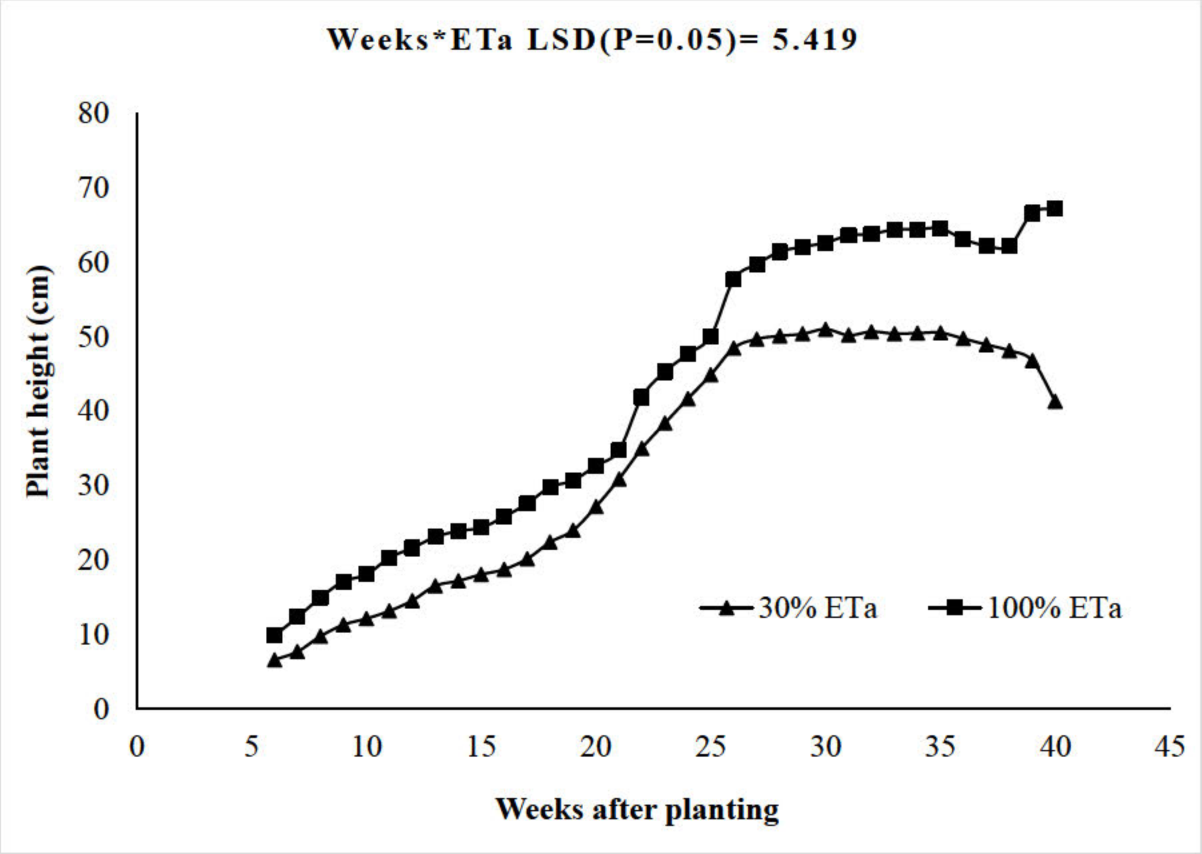

Figure 3.4: Plant height of a taro landrace [Umbumbulu (UM)] in response to water treatments (30% and 100% ETa) under controlled environment conditions during the 2018/19 season.

3.3.3 Leaf area

Leaf area per plant was affected by water treatments (P<0.05). There were highly significant differences (P<0.001) between the interaction of water treatments and time (WAP) with regards to leaf area length (Figure 3.5). The 100% ETa had significantly higher leaf area length than 30% ETa based on the mean values; however, the 30% ETa was shown to have decreased by about 38.8% relative to the 100% ETa treatment (Figure 3.5).

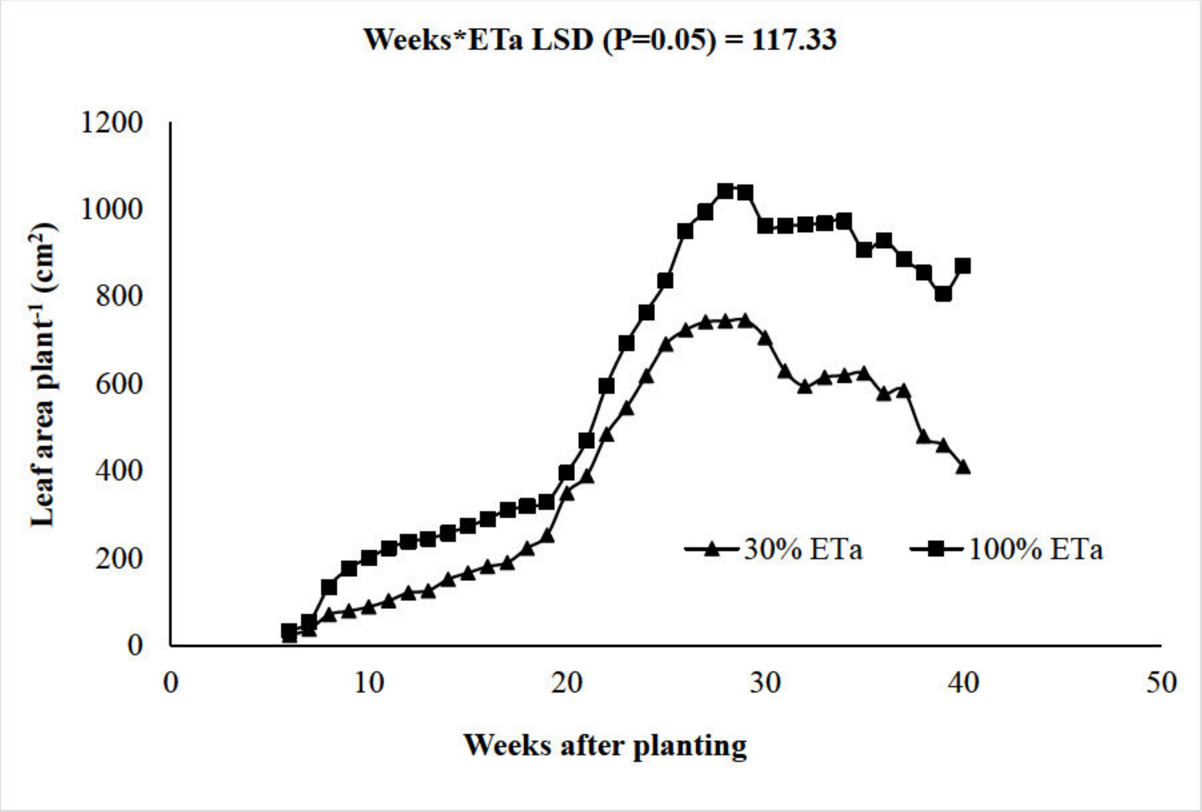

Figure 3.5: Leaf area index of taro landrace [Umbumbulu (UM)] in response to water treatments (30% and 100% ETa) under controlled environment conditions during the 2018/19 season.

3.3.4 Leaf number

The results of the leaf number showed highly significant differences (P<0.001) between the interaction of water treatments and time (WAP). This was similar to plant height and leaf area where the interaction of water treatments and time (WAP) was observed to be highly significant (P<0.001) (Figure 3.4 and 3.5). A sharp decrease in leaf number was observed from 26 WAP at 30% ETa; however, it was also interesting to observe a sudden decrease in leaf number from 27 WAP under high water treatment (Figure 3.6). The 100% ETa displayed a significantly higher number of leaves per plant (4.181 leaves) than 30% ETa (3.467 leaves), with a decrease of about 18.7% at 30% ETa relative to the 100% ETa treatment based on the mean values (Figure 3.6).

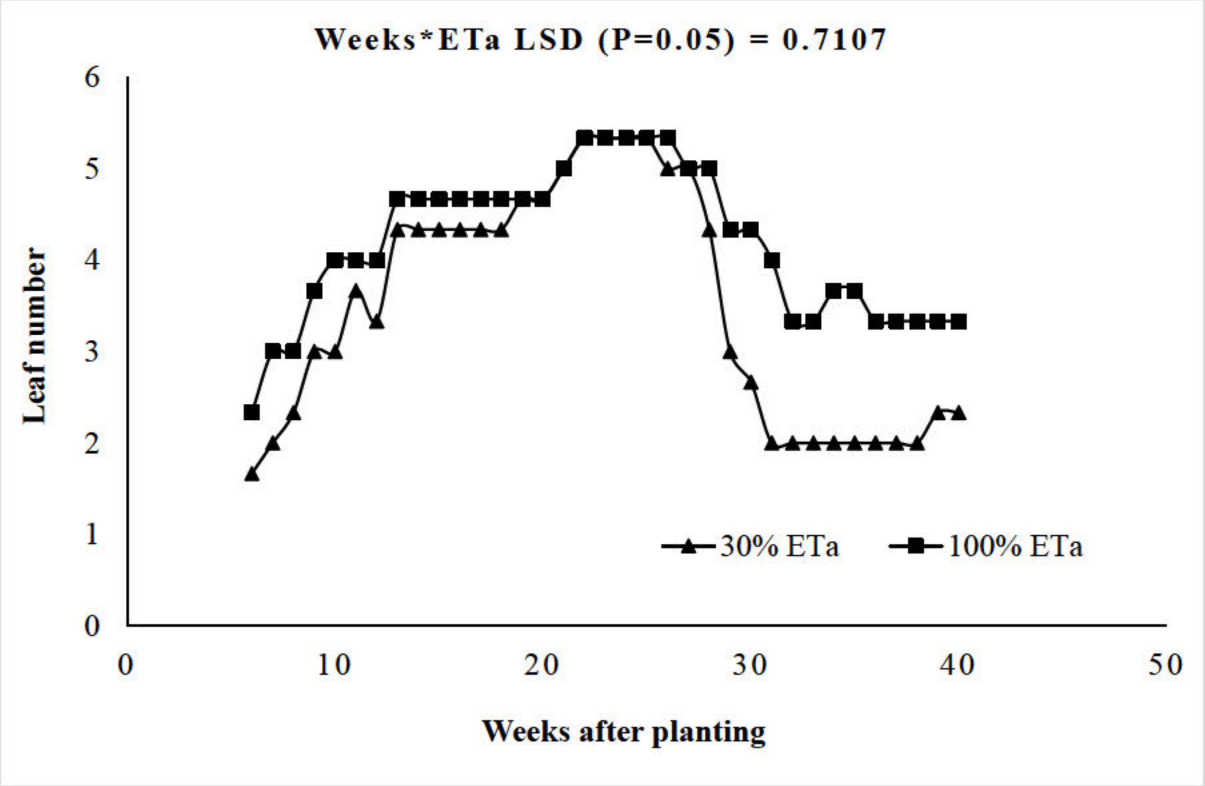

Figure 3.6: Leaf number of taro landrace [Umbumbulu (UM)] in response to water treatments (30% and 100% ETa) under controlled environment conditions during the 2018/19 season.

3.3.5 Chlorophyll content index

Highly significant differences (P<0.001) were observed for CCI over time (Figure 3.7). The interaction between water treatments and time (WAP) observed during the study was highly significant (P<0.001). Chlorophyll content index was shown to decrease at 30% ETa treatment overtime. The CCI was higher at 100% than at 30% ETa; however, at 30% ETa the trend of results showed that CCI decreased by about 2.5% relative to the 100% ETa treatment, based on the mean values (Figure 3.7).

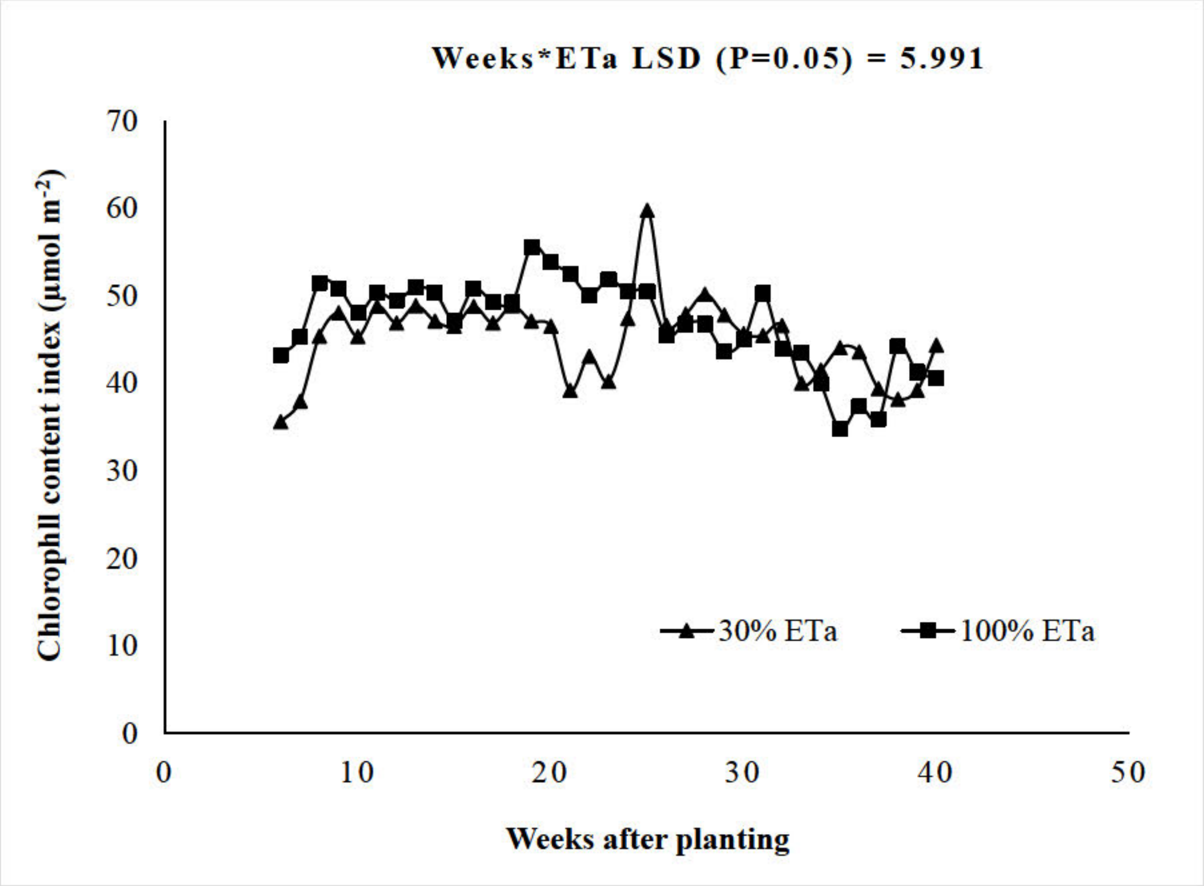

Figure 3.7: Chlorophyll content index of taro landrace [Umbumbulu (UM)] in response to water treatments (30% and 100% ETa) under controlled environment conditions during the 2018/19 season.

3.3.6 Chlorophyll fluorescence

The interaction between water treatments and time (WAP) indicated significant differences (P = 0.002). Chlorophyll fluorescence was not significantly affected (P>0.05) by water treatments (Figure 3.8). The landrace UM showed no significant differences (P>0.05). The Fv/Fm values, which indicated the maximum quantum yield of PS 2 measured at 30% ETa, was about 0.8% higher relative to the 100% ETa treatment, indicated by the trend of results (Figure 3.8). Overall, the results of CF pointed to the 30% ETa having higher effective quantum yield, in response to decreasing water availability than at 100% ETa treatment under high water availability.

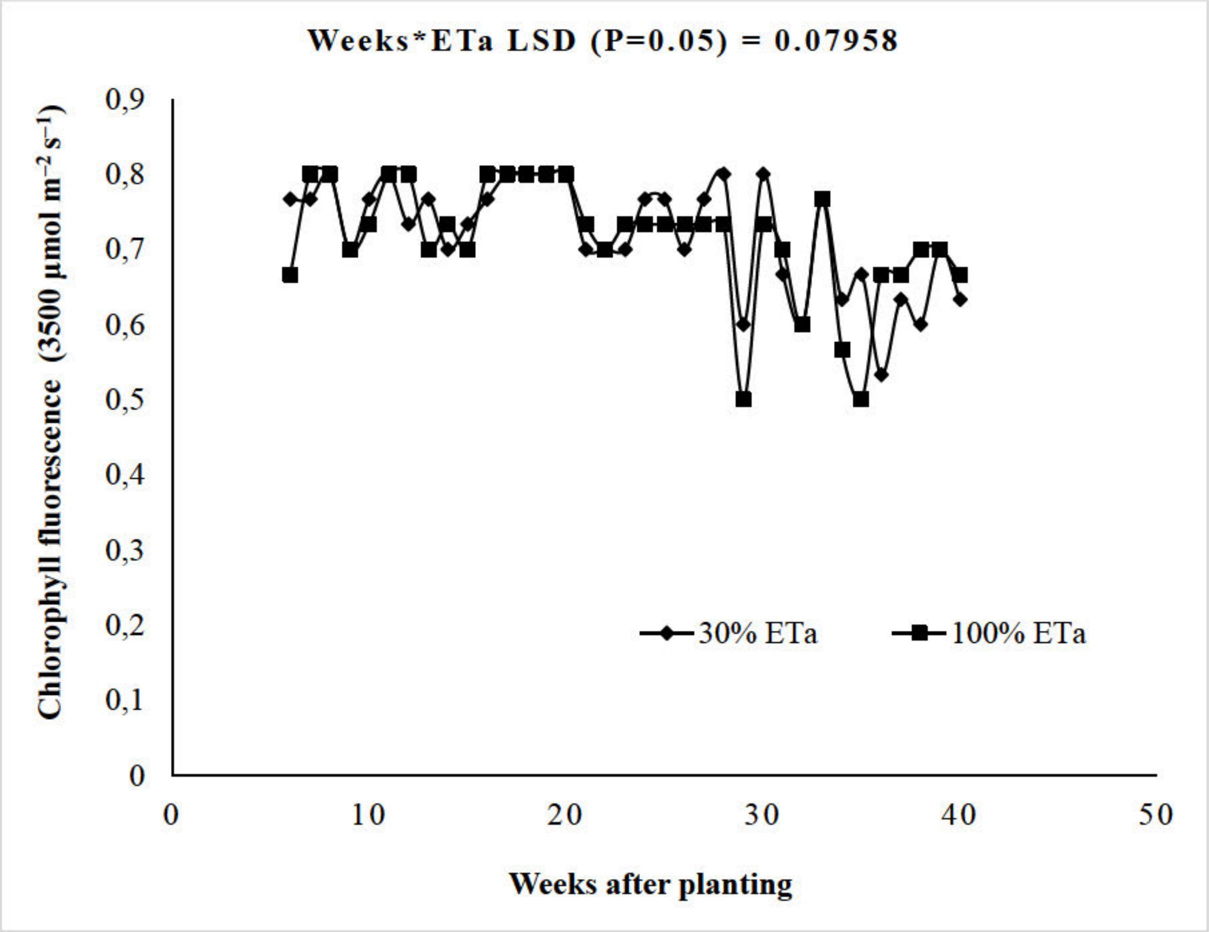

Figure 3.8: Chlorophyll fluorescence (CF) of taro landrace [Umbumbulu (UM)] in response to water treatments (30% and 100% ETa) under controlled environment conditions during the 2018/19 season.

3.3.7 Stomatal conductance (SC)

Stomatal conductance was significantly affected ($P<0.001$) by water treatments (Figure 3.9). Taro landrace showed no significant differences ($P>0.05$). The interaction between water treatments and time (WAP) showed highly significant differences ($P<0.001$). SC measured at 30% ETa, was 22.4% lower relative to 100% ETa treatment (Figure 3.9). Overall, results of stomatal conductance pointed to the 100% ETa having greater stomatal regulation, than at 30% ETa treatment.

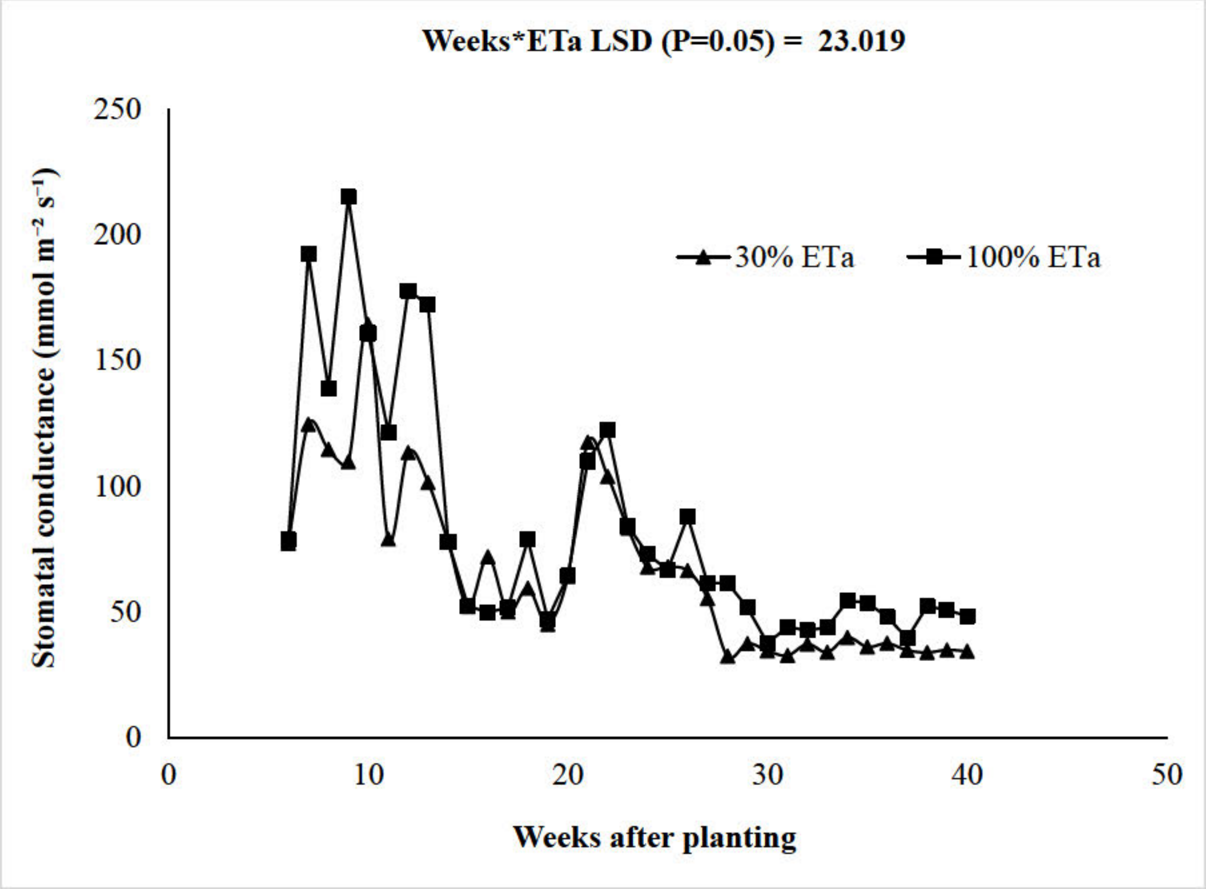

Figure 3.9: Stomatal conductance (SC) of taro landrace [Umbumbulu (UM)] in response to water treatments (30% and 100% ETa) under controlled environment conditions during the 2018/19 season.

3.3.8 Soil water content (SWC)

Results of SWC varied significantly between water treatments, with SWC being higher at 100% relative to the 30% ETa treatment (Figure 3.9). The interaction of water treatments and time (WAP) was significant (P = 0.002) with respect to SWC. The SWC at 30% ETa was averaged at 31.2% relative to 100% ETa with 36.8% from 6 WAP up to 20 WAP (Figure 3.10). The SWC was significantly higher under high water treatment (100% ETa) with an average rate of 35.88% than at water stress conditions (30% ETa), with about 29.49% recorded over the growing season. The soil water content at 30% ETa decreased with about 19.6% relative to the 100% ETa treatment, based on the mean values (Figure 3.10).

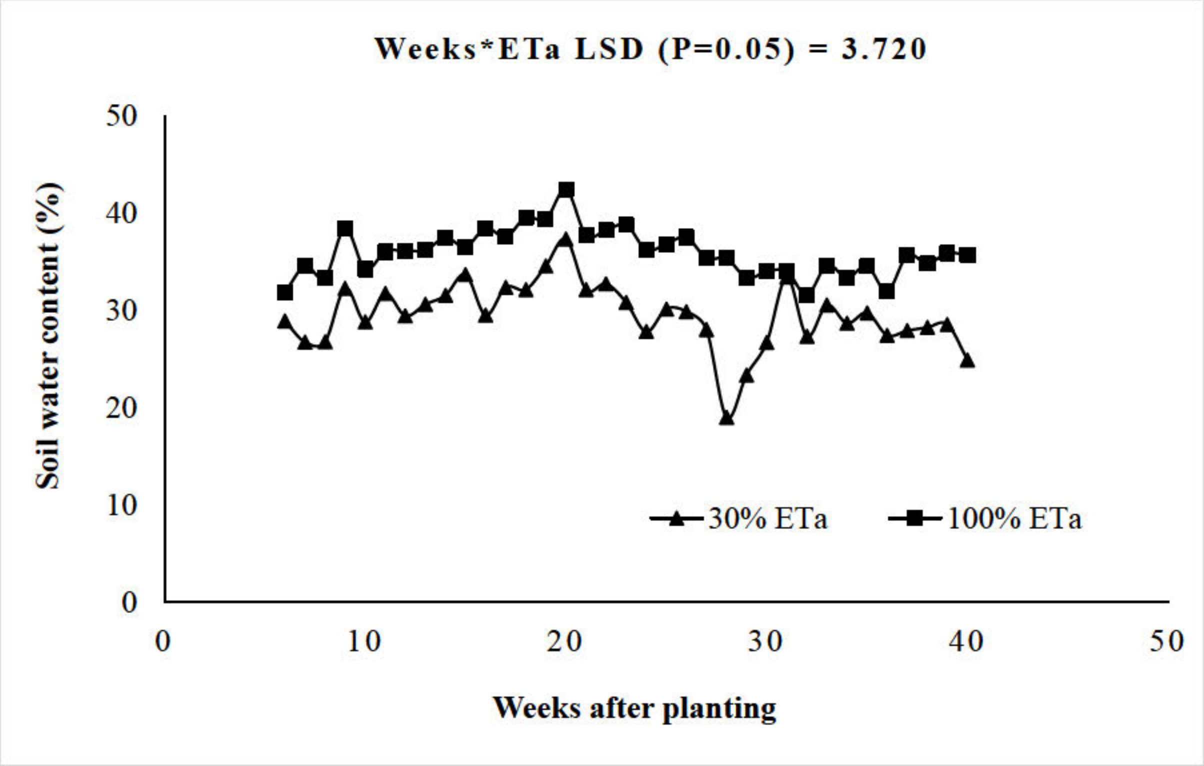

Figure 3.10: Soil water content (SWC) of taro landrace [Umbumbulu (UM)] in response to water treatment (30% and 100% ETa) under controlled environment conditions during the 2018/19 season.

3.3.9 Yield and yield components

The trend in final yield and yield components was consistent with trend results for plant growth parameters reported in the study above. Results of yield and yield components included (biomass, corm mass, corm number, and harvest index), water use efficiency, and water productivity, which showed that taro landrace responded differently to different irrigation treatments (Table 3.4). Yield and corm mass per plant varied significantly ($P<0.05$) between the two irrigation treatments (Table 3.4). Irrigation treatments had a significant effect ($P<0.001$) on biomass, corm mass, corm number, and HI (Table 3.4). UM landrace had the highest biomass (1.414 kg/plant), corm mass (1.018 kg/plant), corm number (23.54) and the HI (73.27%) at 100% ETa, compared to 30% ETa water treatment with the lowest biomass (0.53 kg/plant), corm mass (0.312 kg/plant), corm number (11.92), and the HI (59.07%) respectively (Table 3.4). HI, on average, was observed to be higher (24%) under well-watered conditions than at limited water conditions. The fact that HI was low under limited water conditions that implied a negative effect of stress on HI while indicating a positive effect under well-water conditions.

The final yield kg per hectare result was consistent with the results of yield components reported above, where it showed highly significant differences ($P<0.001$) with respect to different water treatments. Water treatments were shown to have a highly significant effect ($P<0.001$) on final yield, with the yield observed lower under water stress conditions compared to well-watered conditions (100% ETa> 30% ETa). The extent of yield reduction on average was higher at 30% than at 100% ETa, the yield was (226%) lower at 30% than at 100% ETa treatment. There were no significant differences ($P>0.05$) on water productivity with respect to landrace and two water treatments (30 and 100% ETa). However, limited water conditions had the highest (7.79 kg m^{-3}) water productivity compared to high water conditions (6.49 kg m^{-3}) (Table 3.4). Water-use efficiency (WUE) showed a significant effect ($P = 0.003$) on two water treatments (30 and 100% ETa). Interestingly, results of WUE showed a different trend than of the final yield and yield components, where water treatment means showed that, on average, WUE was slightly higher by 47% at 30% ETa (132.15 kg ha^{-1} mm^{-1}) compared to 100% ETa (90.21 kg ha^{-1} mm^{-1}).

Table 3.4: Yield and yield components (biomass, corm mass, corm number, and harvest index), water use efficiency and water productivity of taro landrace [Umbumbulu (UM)] in response to water treatments (30% and 100% ETa) grown under controlled environment conditions during 2018/19 season.

Water treatments	Landrace	Biomass plant^{-1} (kg)	Corm mass plant^{-1} (kg)	Number of corms	Yield (kg ha^{-1})	Harvest Index (%)	WUE (kg.ha^{-1} mm^{-1})
100% ETa	**UM**	1.414	1.018	23.54	56543.98	73.27	90.21
30% ETa	**UM**	0.530	0.312	11.92	17358.80	59.07	132.15
Mean		0.972	0.665	17.73	36951.39	66.17	111.18
LSD$_{(P=0.05)}$		0.2600	0.1802	3.096	10010.454	4.175	26.751
CV		46.0	46.6	30.0	46.6	10.8	41.4

*number represents the percentage of crop water requirement

3.3.10 Nutritional content (NC)

According to (Table 3.5), the mineral content of taro cormels was significantly (P< 0.05) affected by the application of different water treatments (30 and 100% ETa). Nutritional content results of the interaction between landrace and water treatment were observed not to be significantly different (P>0.05). There were significant differences observed among the elemental nutrients analysed under different water treatments and those minerals included; aluminium (P = 0.002), copper (P= 0.044), iron (P<0.001), sodium (P<0.001), magnesium (P= 0.052), calcium (P= 0.018), and total nitrogen (P = 0.020) content of taro cormels. The only elemental nutrients that were observed not significant (P>0.05) were boron, calcium, potassium, manganese, carbon, phosphorus, sulphur, and zinc content of taro cormels. It was fascinating, to observe that under water stress conditions the mineral content recorded was higher compared to well-watered conditions and the mineral content included, aluminium (62.93 mg kg^{-1}), iron (83.27 mg kg^{-1}), sodium (14.49 mg kg^{-1}), manganese (0.16 %), calcium (0.17 %) and nitrogen (1.51%). However, under well-watered conditions, copper (4.59 mg kg^{-1}) was the only nutrient observed to be high relative to water stress conditions.

Table 3.5: Nutritional content of macro (N, Ca, Na and Mg) and micro (Fe, Cu, and Al) nutrients of a taro landrace [Umbumbulu (UM)] in response to water treatments (30% and 100% ETa) during the 2018/19 season.

Water treatments	Landrace	Al	Cu	Fe	Na	Mg	Ca	Total N
		................mg.kg^{-1}...................				…............%...............		
100% ETa	**UM**	39.48	4.59	45.77	229.91	0.11	0.09	0.55
30% ETa	**UM**	62.93	3.56	83.27	371.77	0.16	0.17	1.51
Mean		51.21	4.07	64.52	300.84	0.14	0.13	1.03
LSD$_{(P=0.05)}$		4.524	0.962	5.778	11.454	0.053	0.047	0.594
CV		2.5	6.7	2.5	1.1	11.1	10.2	16.4

3.3.11 Nutritional water productivity (NWP)

Nutritional water productivity of the nutrients (aluminium, iron, manganese, sodium, phosphorus, calcium, potassium, magnesium, nitrogen, and sulphur) measured in this study varied significantly ($P<0.05$) between two water treatments (Table 3.6). The only exception was with NWP_{Zn} and $NWP_{C,}$ which did not show any significant differences ($P>0.05$) between water treatment (Table 3.6). NWP results of the interaction between landrace and water treatments were observed not significantly different ($P>0.05$) from each other. NWP was observed to be high under limited water conditions compared to well-watered conditions which included, NWP_{Al} (486.45 mg m^{-3}), NWP_{Fe} (643.33 m^{-3}), NWP_{Mn} (58.90 mg m^{-3}), NWP_{Na}

(2889.41 mg m^{-3}), NWP$_{P}$ (2.54 m^{-3}), NWP$_{Ca}$ (1.31 m^{-3}), NWP$_{K}$ (486.45 mg m^{-3}), NWP$_{Mg}$ (1.23 m^{-3}), NWP$_{Total\ N}$ (25.11 m^{-3}), and NWP$_{Total\ S}$ (0.58 mg m^{-3}). However, these results are interesting that high NWP was observed under water stress conditions relative to well-watered conditions; as a result, this could prove that taro has the potential to produce high nutrition even when subjected to water stress conditions. Thus, the results were not consistent with observations of growth, yield and yield parameters.

Table 3.6: Nutritional water productivity of macro (N, Ca, K, Mg, P, and S) and micro (Al, Fe, Cu, Mn, and Na) nutrients of a taro landrace [Umbumbulu (UM)] grown under two different water treatments (30 and 100% ETa) during 2018/19 season.

Water treatments	**Landrace**	**NWP$_{Al}$**	**NWP$_{Fe}$**	**NWP$_{Mn}$**	**NWP$_{Na}$**	**NWP$_{P}$**	**NWP$_{Ca}$**	**NWP$_{K}$**	**NWP$_{Mg}$**	**NWP$_{Total\ N}$**	**NWP$_{Total\ S}$**
		..........................mg.m-3……….........				**..m-3……………………..................**					
100% ETa	**UM**	255.87	296.29	39.33	1487.33	1.90	0.58	8.31	0.71	3.44	0.20
30% ETa	**UM**	486.45	643.33	58.90	2889.41	2.54	1.31	11.51	1.23	11.25	0.58
Mean		371.16	469.81	49.12	2188.37	2.22	0.95	9.91	0.97	7.35	0.39
LSD$_{(P=0.05)}$		86.226	110.229	11.459	514.208	0.580	0.217	2.151	0.232	1.721	0.147
CV		39.9	40.3	40.1	40.4	44.9	39.3	37.3	41.0	40.3	65.3

3.3.12 Feed starch content of taro cormels

There were significant differences (P = 0.011) among water treatments with respect to starch content. Results of the interaction between landrace and water treatments were observed not significantly different (P>0.05) from each other with respect to starch content. Starch content was observed to be high under high water treatment (60.04%) compared to limited water conditions (52.67%) (Table 3.7).

Table 3.7: Feed starch of taro landrace [Umbumbulu (UM)] grown under two different water treatments (30 and 100% ETa) during the 2018/19 season.

Water treatments	Landrace	Feed Starch (%)
100% ETa	**UM**	60,04
30% ETa	**UM**	52,67
Mean		56.36
LSD$_{(P=0.05)}$		3.337
CV		1.7

3.4 Discussion

The objective of the study was to determine the effect of different water levels on growth, development, yield, and yield quality (WUE, WP, and NWP) of *Umbumbulu* taro landrace under controlled environment conditions. The taro landrace investigated under this study responded differently to different water treatments, and as a result that influenced the crops' development, yield, WP, and NWP. Soil water content varied significantly between the two water treatments (30% and 100% ETa), where the SWC results showed a higher SWC under well-watered conditions than under stress water conditions. However, this was true to expectation as similar findings were observed by Sibiya (2015), under stress water conditions, SWC was reported to be lower relative to well-watered conditions. The results of crop establishment indicated that water availability affected taro emergence (Figure 3.3). Taro landrace *Umbumbulu* used in the study reported having emerged faster under well-watered conditions relative to water stress conditions, where emergence was higher under well-watered conditions than in limited water conditions. As mentioned in the literature, taro requires water and moisture in the soil to be adequately available together with better environmental conditions to emerge well for better crop stand.

Under well-watered conditions within 45 days, more than 80% of corms sprouted using drip irrigation, while Sunitha *et al*. (2013) reported that 77% of taro corms sprouted within 45 days after planting using drip irrigation. Under well-watered conditions, it took about 63 days after planting to reach 100% emergence, while under limited water conditions, it took about 77 days after planting to reach 100% taro landrace emergence. Slow emergence observed within limited water conditions as compared to well-watered conditions, suggests that a significant volume of water could be lost to soil evaporation in contrary to being lost through transpiration during crop establishment (Blum, 2009; Mabhaudhi, 2012). The use of drip irrigation in the study has allowed a smaller percentage of the wetted soil surface, which is inclined with saving water (Phene *et al*., 1994; Unlu *et al*., 2006; Mabhaudhi, 2012). However, ensuring the good seedling establishment is favourable for a rapid ground cover, which could result in reducing the loss of water to soil evaporation (Passioura, 2006).

Plant height showed significant differences between water treatments and WAP (Figure 3.4). *Umbumbulu* a single landrace used in the study, had tall plants at 100% than at 30% ETa water treatment and these were similar findings that were observed by Mabhaudhi *et al*. (2013) on taro in response to water stress. The loss of cell division and expansion is highly influenced by limited water availability, and that will result in reduced plant growth (Hussain *et al*., 2008; Mabhaudhi, 2012). Canopy size is known to represent the surface area available for transpiration, as the results, plants under limited water conditions tend to reduce their canopy and plant size in order to cope with water stress in the form of a dehydration avoidance mechanism (Levitt, 1980; Turner, 1986; Mitchell *et al*., 1998; Mabhaudhi, 2012). Leaf area is known to be directly correlated to biomass production as well as yield (Blum, 2005). In this regard, a plant characterised with a reasonable reduction in canopy size is able to maintain well a balance between minimising water while continue to maximise optimum biomass production over time (Mabhaudhi, 2012).

However, reduced leaf area per plant reported under limited water conditions compared to well-watered conditions is highly attributed to a reduction in photosynthesis, which also contributes to reduced leaf expansion (Anjum *et al*., 2011). A reduction in leaf number is a result of premature senescence of leaves during the growth of taro (Mabhaudhi, 2012). The trend indicated lower canopy size (plant height, leaf number, and Leaf area) under stress water conditions which proved to be consistent with the reports by Sivan (1995) and Sahoo *et al*. (2006), that reduce plant growth, leaf number and the leaf area in taro varieties were observed under stress water conditions (Figure 4.4, 4.5 and 4.6). Overall, this study showed that leaf area, leaf number, and plant height were all lower under limited water conditions.

Chlorophyll content index (CCI) varied significantly over time between the two water treatments. The CCI can be used as the maturity index as it tends to increase during the vegetative stage and decreases towards the maturity stage. It was indicated from the study that CCI decreased under limited water conditions relative to well-watered conditions, and that was also in line with decreasing stomatal conductance. However, these findings prove to be true with Sahoo *et al*. (2006) and Mabhaudhi *et al*. (2013), who observed a decrease in CCI in a taro landrace under stress water conditions. The results were expected where a decrease in CCI under stress water conditions was in the form of down-regulation of photosynthesis, which also results in decreasing carbon dioxide (CO_2) availability (Mabhaudhi *et al*., 2013).

In the study, chlorophyll fluorescence (CF) analysis was used to determine plant photosynthetic efficiency and also to allow for characterisation of light under stress conditions (Flexas *et al*., 2002; Kitao *et al*., 2003; Chowdhury *et al*., 2009). The maximum quantum yield of PS 2 (Fv/Fm) did not significantly differ that much between limited water conditions relative to well-watered conditions during the growing season. However, the trend of results indicated the maximum quantum yield of PS 2 under stress water conditions being higher relative to well-watered conditions (Figure 3.7). This suggests that under stress water conditions, leaves were able to adopt different strategies to utilise their maximum quantum yield potential more effectively relative to those at the well-watered conditions. Under limited water conditions, it has been reported that stimulation of separating electron flow to pathways other than CO_2 assimilation within the plants is likely to occur compared to well-watered conditions (Park *et al*., 1996, Kitao *et al*., 2003; Chowdhury *et al*., 2009). Under limited water conditions, plants were able to absorb energy effectively; as a result, the higher effective quantum yield of photosystem PS 2 was achieved relative to well-watered conditions.

Stomatal conductance (SC) varied significantly over time (WAP) between two water treatments. Stomata facilitate water loss in the form of transpiration, together with the uptake of CO_2 from the atmosphere (Mabhaudhi, 2012). The study revealed that SC decreases in response to decreasing water availability, where lower SC was observed under limited water conditions compared to well-watered conditions. This was true to expectation where similar findings under the same conditions were reported by Motsa *et al.* (2015), working on sweet potato cultivars, where lower SC was observed under limited water conditions relative to well-watered conditions. Similar findings were also reported by Sivan (1995) and Mabhaudhi (2012) that SC of taro varieties was observed decreasing under water stress conditions. The decrease in SC under water stress conditions is the mechanism that plants use to minimise water loss due to transpiration. In addition, this can be translated to dehydration avoidance (Levitt, 1980; Turner, 1986; Chaves *et al*., 2003).

Yield and yield parameters (biomass, corm mass, corm number, and HI) results showed that taro landrace responded differently and varied significantly within different water treatments (Table 3.4). The trend of yield and yield components results under stress water conditions showed to be consistent with crop growth results (leaf number, plant height, and leaf area), as these parameters were observed to be decreasing in response to reduced water availability. After all, these findings differ from a study reported by Sibiya (2015), who observed higher corm mass and number of corms per plant under limited water conditions. It was reported that taro grown under different water treatments affected the corm formation during the growth phase, especially under limited water conditions and that resulted negatively in yield (Uyeda *et al.*, 2011; Byrd *et al*., 2014). A study by Mabhaudhi; Badr *et al*. (2014), observed a similar trend on reports of yield and water use efficiency of potato grown under different irrigation levels, that decreasing the total amount of irrigated water applied will lead to a decrease in tuber yield. Therefore, the alternative hypothesis of the study with respect to final yield was rejected, since the 30% ETa water treatment obtained a lower final yield of taro landrace compared to 100% ETa water treatment.

Taro plants under limited water conditions reached maturity stage earlier, and harvesting was done on January 2019 compared to well-watered conditions where it was done late on February

2019. Taro plants may have reached maturity earlier under stress water conditions through demonstrating drought avoidance by reducing canopy size and by the escape mechanism through phenological plasticity, in the form of reducing crop water losses to transpiration (Levitt, 1980; Turner, 1986; Mitchell *et al*., 1998; Mabhaudhi, 2012). For optimum water conditions, late maturity resulted in low WUE and NWP but with high biomass; while under limited water conditions, early maturity resulted in high WUE and NWP but lower biomass. This was different from the findings by Chibarabada (2018), who observed that late maturity in groundnut led to high water use, which also translated to high biomass. A significant higher HI under optimum water conditions proved that taro was capable of converting biomass economic yield more efficiently than under limited water conditions. HI was observed to be more sensitive to changes in biomass production compared to the corm number, and the HI was higher under well-watered conditions compared to limited water conditions. The current study demonstrated that biomass is the greatest contributor to yield, and as the results, the biomass production was affected by water stress with a reduction in growth parameters, such as stomatal conductance and chlorophyll content, reduced vegetative growth, and crop duration. This proves that agronomy management practices that will improve biomass production should be implemented and mainly practiced to maximise yield under water stress conditions.

There was no significant effect observed with respect to WP, but the study showed that under limited water conditions, WP was high compared to well-water conditions. This could be the result that under limited water conditions, the process of photosynthesis was more efficient compared to optimum water conditions, and the results were supported by the improved WUE and NWP under limited water conditions. Thus, many reports have emphasised and recommended that less water should be applied to maximise crop WP which automatically improves crop NWP (Fereres and Soriano, 2007; Hirich *et al*., 2011; Rodrigues and Pereira, 2009; Sarwar and Perry, 2002; Zwart, 2013). On average, limited water conditions had higher WUE (132.15 kg. ha^{-1} mm^{-1}) almost double of that well-watered conditions (90.21 kg. ha^{-1} mm^{-1}). However, a possible explanation to these interesting findings could be the type of landrace used in the study or perhaps how water stress was imposed in relation to this study. Previous studies have highlighted, especially under limited water conditions, that WUE will result in an increase only when yield (biomass) is either increasing or when the water use the amount of total irrigation water applied is decreased (Pandey *et al*., 2000; Durand, 2006; Mabhaudhi, 2012).

As mentioned in the literature mineral composition of taro differs throughout the entire parts of the plant, but the genotype, age of the plant, environmental conditions and the interaction between the genotype and the environment are regarded as contributing factors to variation of nutritional composition in taro corms (Wills *et al*., 1983; Mwenye *et al*., 2011; Mergedus *et al*., 2015). The total composition of proteins and minerals of taro considered as vital are reported to play a major role in the human diet (Mare, 2009). Previous studies investigating taro mineral composition have emphasised potassium as mineral available in large quantities (Mergedus *et al*., 2015). However, minerals such as calcium, magnesium, and phosphorus have been found to be also available in large quantities in taro corms (Bradbury & Holloway, 1988; Huang *et al*., 2007; Lewu *et al*., 2010; Mwenye *et al*., 2011). While on the other hand nutritional observation showed iron and manganese to be present in low quantities in taro corms (Lewu *et al*., 2010; Mwenye *et al*., 2011). The elemental nutrients result in (Table 3.5) showed the significant differences in different water treatment except for, calcium (Ca), potassium (K), manganese (Mn), carbon (C), phosphorus (P), sulfur (S) and zinc (Zn) content of taro cormels. The mineral content was recorded high under limited water conditions compared to well-watered conditions; however, copper (Cu) was the only nutrient observed to be high under well-water conditions.

Overall, the study objective was investigated, and that different water treatments had a significant effect on growth parameters, yield and yield parameters, WUE and NWP while, the interaction of landrace and water treatments did not show any significant effects. For NWP (Al, Fe, Mn, Na, P, Ca, K, Mg, Total N, and Total S) were all the elemental nutrients available in low quantities under well-watered conditions due to poor nutrient content compared to limited water conditions, even though the yield was observed high under 100% ETa than at 30% ETa water treatment. Thus, low corm yield could result in low NWP, with more emphasis being placed on improving yield stability as a form of eliminating food insecurity. It has been recommended that in order to improve WP which also result in an improved in NWP under water-scarce environment better management skills need to be highly practised such as, improved irrigation management, growing appropriate crops and genotypes and better agronomic practices (Passioura, 2006; Molden *et al*., 2010; Karrou and Oweis, 2012;

Descheemaeker *et al*., 2013; Estrada *et al*., 2015). Therefore, the alternative hypothesis of the study with respect to nutritional yield was accepted, since the 30% ETa water treatment obtained a higher nutritional yield of taro landrace than the 100% ETa water treatment.

Supported by the literature, taro is reported as one of the tubers and root crops that contain more starch, about 80% amylopectin with 22 glucose units per molecule, and 20% amylose with 490 glucose units per molecule (Mae, 2006). The starch level in taro is reported to range between 70 – 80% (TU *et al*., 1979; Modi, 2004). A study by Onwueme and Charles (1994), previously indicated that approximately 13 – 29% of fresh corm carbohydrates 77.9% is being recognised as starch which is produced in very small starch grains making it easy for its digestibility (Quach *et al*., 2001; Van Wyk, 2005; Ahmed and Khan, 2013). Overall, the starch content was observed to be high under optimum water conditions than at limited water conditions. As a result, with respect to starch, the null hypothesis of the study was rejected since the starch content was recorded high at 100% than at 30% ETa water treatment. As stated from the literature, the starch content of tuber and roots crops is more influenced by environmental conditions such as, high temperatures which decrease the rate of photosynthesis but increasing respiration rate and that resulting in a decrease of starch content (Mare, 2009).

3.5 Conclusion

The importance of better crop emergence in taro is considered vital as that would play a significant role in improving water-use and possibly yield. Water use efficiency was higher under limited water conditions relative to well-watered conditions with that, the crops were able to produce reasonable yields under limited water conditions, and that resulted in improvements in WP and NWP under limited water conditions. The findings of the study indicated the possibility of taro landrace production to improve food security and malnutrition especially within the developing countries. The benefit of growing taro is the ability to survive under water-logged environmental conditions where many crops fail as a result the crop become desirable for areas experiencing poor agricultural technology. Overall, high water conditions outperformed limited water conditions with respect to growth parameters, yield, HI, and starch content, while the WUE and NWP were high under limited water conditions. Under conditions of limited water availability, taro landrace was able to reduce their water use through reductions in stomatal conductance and canopy size. The extent of reduction in canopy size was greater under limited water conditions compared with optimum water conditions suggesting that the taro landrace was more sensitive to limited water availability. Under limited water conditions, stomatal conductance was controlled through minimising water loss in the form of transpiration. As a result, photosynthesis and biomass accumulation were negatively affected due to low levels of carbon dioxide entering the plant. However, future studies need to consider different strategies such as intercropping, mulching, and perhaps increasing planting density as the form of minimising the effect of soil evaporation to make taro more desirable for farming.

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CHAPTER 4

THE EFFECT OF PLANTING DATE AND FERTILISATION ON GROWTH, DEVELOPMENT, AND YIELD OF TARO LANDRACES UNDER FIELD CONDITIONS.

4.1 Summary

Taro (*Colocasia esculenta* L. Schott) is classified as one of the essential traditional crops mainly grown for its starchy corms throughout the rural areas of South Africa especially in Bizana district in the Eastern Cape and the coastal area of KwaZulu-Natal (KZN) as well as to other rural subtropical (sunny and very warm weather conditions) and tropical (very hot) regions of the world (Vinning, 2003; Hancock, 2004). However, recent evidence suggests that the value of the crop's contribution to food security is still limited due to ack of scientific research related to its commercialisation and agronomy (Hancock, 2004). Taro can be grown under different environmental conditions. When it is grown under rainfed conditions is estimated to take approximately 6 to 12 months to reach maturity (Miyasaka *et al*., 2003; Mare, 2009). Studies have found taro corm to be the valuable part where corm quality is critical when considering taro for processing, as there is an initiative from the emerging market of taro in KZN to process taro into crisps. According to Mare (2009), planting date, fertilisation, cultivar including Triggs *et al*. (2004) the environmental conditions all are considered as vital factors influencing corm or tuber quality whereas, a variety of taro cultivars are grown organically but at different planting dates.

However, response to planting date is mainly influenced by the cultivar, where different environmental conditions are a result of different planting dates and the use of different organic fertiliser rates together to influence the corm quality of the cultivars (Mare, 2009). Recent evidence by Mohamed (1985) and Mare (2009) suggested that delaying planting from the first planting date, the protein content of the tubers was recorded higher regardless of the landrace. Planting date and fertilisation have the ability to influence crop growth performance, irrespective of whether the crop is landrace or an improved cultivar. The mineral content, including nitrogen, phosphorus, and potassium content as well as dry matter content, protein content, and specific gravity were all increased by the application of farmyard manure (El-Sirafy *et al*., 2008). Some studies have shown water availability and temperature at different

sites and planting dates to have influenced the yield of root crops (Lu *et al*., 2001; Khan *et al.*, 2003; Scheffer *et al.*, 2005; Kumar *et al.*, 2007; Hagman *et al.*, 2009).

Tuber yield is mainly influenced by moisture and temperature, fertilisation and landrace, thus planting taro at the appropriate planting date together with using proper fertilisation and landrace is likely to improve taro plant growth as well as yield quality. It was hypothesized that different planting dates would influence the final yield and nutrition of taro landrace. The objective of this study was to investigate the effect of planting date and fertilisation on growth, development and yield quality of taro landraces found in Umbumbulu, KwaZulu-Natal under field conditions.

4.2 Materials and Methods

4.2.1 Planting material

The two taro landraces of the eddoe type *Mgingqeni* (MG) and *Pitshi* (PI) shown in Figure 4.1 were used for the field study with three planting dates, namely October, November and December. The cormel size of the taro plants varies between and within cultivars or landraces. Local taro landraces were sourced from smallholder farmers of Ezigeni, at Umbumbulu district (28°55' S, 31°42' E) in the Midlands location of KwaZulu-Natal (KZN). Both MG and PI taro landraces were classified as upland landraces (the eddoe type) characterised by a central corm and several side cormels, which are the edible parts and are propagated using sprouted corm and head setts (Lebot, 2009; Mabhaudhi, 2012). The eddoe type landrace is generally known to take about six months to mature, however under rainfed conditions, it can be extended even further up to 8 to 10 months depending on the season and the location (Sibiya, 2015).

Figure 4.1: Taro landraces varieties *Mgingqeni* (MG) and *Pitshi* (PI) of KwaZulu-Natal (Mare, 2009).

4.2.2 Site descriptions

The field trial experiment was carried out at a single location, Ukulinga Research Farm (29°37'S; 30°16'E, and 805 m above sea level) in Pietermaritzburg KZN. The field trial was established during the summer season of October 2016, November 2018 and December 2018 under rain-fed conditions. Ukulinga farm is characterised as the area that has a subtropical climate with 694 mm mean annual rainfall mainly received during the summer season (October – March), and it also has a semi-arid environment with sandy clay loam soils (Sibiya, 2015). Temperature and rainfall data for Ukulinga farm was obtained from an automated weather station (AWS) for the duration of the experimental period, as indicated in Table 4.1.

Table 4.1: Ukulinga Research Farm data for temperature and rainfall for the duration of the experimental period.

Sites		Total	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Ukulinga	**Rainfall (mm)**	693,9	80,3	82,3	106,8	105,2	83,5	87,7	42,4	17,4	10,4	8,5	29,1	40,3
	Temp Min (°C)	157,7	12,9	14	16,1	17,1	17	16	13,1	11,9	9,1	8,7	10,3	11,5
	Temp Max (°C)	294,3	23,9	24,3	25,7	27	27,7	26,8	24,3	24,1	21,4	21,1	23,5	24,5
	Temp Mean (°C)	215,7	17,5	18,3	19,9	21	21,4	20,8	17,9	17,2	14,5	14,1	16	17,1

4.2.3 Experimental layout and design

The experiment was set up in a factorial design layout in completely randomized block design (CRBD) with three replications. The factors includes three organic fertiliser Gromor Accelerator® application rates [no organic fertiliser (0 N kg per hectare), low organic fertiliser (160 N kg per hectare) and high organic fertiliser (320 N kg per hectare)], with three planting dates (12 October 2018, 16 November 2018 and 10 December 2018) and two taro landraces MG and PI were used in the study. The selection of factors was based on the literature on growth of taro (Lebot, 2009; Miyasaka *et al.*, 2003). The planting density used was 0.5 m between and 0.9 m within rows (22 222 plants per hectare), where individual plots size was measured to be 8 m² (4 m x 2 m) containing 27 plants per plot.

Figure 4.2: Taro landraces (UM and PI) planted under field conditions at Ukulinga Research Farm.

4.2.4 Data collection

4.2.4.1 Physiological measurements

Physiological measurements were done weekly before the midday irrigation event (between 11 am and midday). A random sample of four plants from the field trial of each experimental plot was considered to determine crop growth and development parameters involving emergence, leaf number, plant height, leaf area, chlorophyll content index (CCI), stomatal conductance (SC), soil moisture content (SWC), photosynthetically active radiation (PAR), as well as yield and yield components. Crop growth and development data were collected every week up until the stage of harvest. Emergence was defined as the protrusion of the shoot through the seed corm, 2 mm above the soil surface (Sibiya, 2015). Emergence was recorded when at least 90% of seedlings have emerged. Leaf number was counted only for fully formed, fully unfolded leaves with at least 50% green leaf area. Plant height was measured from the soil surface up to the base of the second youngest, fully formed, fully unfolded leaf. Leaf area per plant (A) was measured using a centimetre ruler, the product of leaf length (L) and leaf Breadth (B).

$$\mathbf{A = L * B\ (cm^2)} \qquad \textbf{Equation 4.1}$$

Where: A = Leaf area plant^{-1} in cm^2, L = leaf length in cm, and B = leaf breadth in cm.

Chlorophyll content index was measured on the adaxial surface of the second youngest fully formed, fully unfolded actively photosynthesizing leaves using a SPAD 502Plus chlorophyll content metre (Konica Minolta, USA). Stomatal conductance was measured during the midday using a steady state leaf porometer model SC-1 (Decagon Devices, USA); measurements were taken on the abaxial leaf surface of the 2nd youngest fully unfolded leaf (Sivan, 1995). Soil moisture content was measured weekly using ML–3X Theta Probe connected to an HH2 handheld moisture meter (Delta-T Devices, UK). In each plot, three probes were carefully inserted within the root zone at an angle (<90◦) then buried with soil. In order to determine plant photosynthetic efficiency, photosynthetically active radiation (PAR) was measured weekly using an LP-80-AccuPAR sensor.

4.2.4.2 Yield and yield components

Taro plants for field trials were harvested 215 days after planting for October, November and December planting dates respectively. Corm yield and other yield parameters were determined when 5 plants were harvested from each experimental plot and the yield and yield components such as biomass (B), the number of corms per plant, total corm mass per plant, harvest index (HI) and corm yield (Y) were determined at harvest. Biomass was determined by weighing the shoot together with roots and corms. Corm yield was determined by weighing edible corms, and HI was then calculated as the proportion of Y to B, where Plants were carefully dugout to avoid damaging roots. The yield was then converted to kg per hectare.

4.2.4.3 Determination of nutritional content

To preserve nutrients and avoid further metabolic reactions, samples were dried at 55°C in a Yamato DKN600 mechanical convection oven with forced-air circulation (60 cm × 50 cm × 50 cm internal dimensions; Yamato Scientific America Inc., Santa Clara, CA); after yield determination. Thereafter, samples were ground using mortar and pestle and sent to the KZN Department of Agriculture and Rural Development Plant Nutrition Laboratory for analysis. The samples were analysed for nutrients on a dry matter basis. The elemental nutrients included macro-nutrients, such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), and micro-nutrients including, Boron (B), copper (Cu), iron (Fe), aluminium (Al), manganese (Mn), zinc (Zn), carbon (C) and sodium (Na). Nitrogen was run on a LECO CNS instrument calibrated with an imported sample and checked against known standard samples. The analyses for calcium, magnesium, potassium, sodium, zinc, copper, manganese, iron, phosphorus and aluminium were done using the I.C.P instrument, which was calibrated on four different levels of imported standards for each of the elements. Internal controls were run every tenth sample, and the instrument was checked regularly using an imported multi element standard (Naramabuye *et al.*, 2008).

4.2.4.4 Determination of starch content

Starch was determined using the enzymatic method of Weinmann (1947) with modifications. Oven-dried, ground material (0.20 g DM) was mixed with 10 ml 80% (v/v) ethanol and homogenized for 60 seconds. Thereafter, the mixture was incubated in a water bath set at 80°C for 60 minutes. Supernatant was suctioned off. These steps were repeated twice then cooled before samples were dried in a Savant Vacuum Concentrator (SpeedVac, Savant, NY, USA). Warm (40 – 50°C) acetate buffer (10 ml) and 200 µl of hexakinase were added to each sample then incubated at 90°C for 30 minutes. Samples were allowed to cool at room temperature before adding 200 µl of G6P-dehydrogenase (G6P-DH) then incubated at 60°C for 20 hrs. Thereafter, samples were vortexed and diluted to 200 ml with distilled water and filtered through Whatman filter paper No. 541. An aliquot (200 µl) of the filtered sample was then taken and diluted further to 3 ml with distilled water. Copper reagent (5 ml) was then added to each sample, vortexed and placed in a boiling water bath for 20 min. Arsenomolybdate (5 ml) was then added to each sample after cooling, vortexed, and left to stand at room temperature for one and a half hours. Samples were diluted (with distilled water) to 200 ml, agitated and read at 750 nm.

4.2.5 Agronomic practices

For land preparation, soil samples were taken before planting and submitted for soil fertility as well as textural analyses to Cedara College. Soil samples were collected from Ukulinga site and analysed, according to Naramabuye *et al.* (2008). Soil sample results are indicated in Table 4.2, showing a soil pH that was below the range, 6 - 6.5 at which taro is known to grow best. According to Mokolobate and Haynes (2002), and Naramabuye *et al.* (2008), organic manure that was applied before planting was associated with increasing soil the pH up to the desirable range where taro is known to grow best. During land preparation at Ukulinga farm, and the activities involved included ploughing and disking the soil to assist in achieving fine soil particles. Gromor accelerator fertiliser was applied using the application rates of 0; 160 and 320 N kg per hectare. Planting holes were opened using a hand-hoe, and organic fertiliser was mixed with soil before cormels were planted per planting station. Sowing was done by hand on ploughed and harrowed fields. Periodic weeds and ridging were done using a hand-hoeing when it was necessary. Harvesting was done eight months after planting.

Table 4.2: Soil sample test results prior to planting at Ukulinga Research Farm Station

Sites	**P**	**K**	**Ca**	**Mg**	**Zn**	**Mn**	**Cu**	**pH**	**Org. C**	**N**	**Clay**
	…............................ mg. L^{-1}…................................							**(Kcl)**	**…..........% ….........**		
Ukulinga field	25	160	857	304	40	50	8.0	3.99	0.15	1.8	31

4.2.6 Statistical analysis

Data was collected and statistically analysed during the season by using the computer statistical program GenStat® (Version 18, VSN International, UK). Analysis of variance (ANOVA) was employed to test the overall significance of the data, while the least significant difference (LSD) test at $P= 0.05$ was used to compare the differences among treatment means.

4.3 Results

4.3.1 Crop establishment

Highly significant differences ($P<0.001$) were observed between planting date with respect to taro landraces emergence (Figure 4.3). However, the application of organic fertiliser did not enhance taro emergence, and landraces were observed not significant ($P>0.05$). The interaction of planting dates, landraces, and Gromor Accelerator® application rate was also found to have no effect on the emergence of taro ($P>0.05$). The emergence of an earlier planting date was observed to be significantly higher than that of later planting date. For all the planting dates, the highest emergence rate was observed in November, followed by October and December, where October and November were not significantly different from each other. All the means and including the interaction effect followed by the same letter are not significantly different from each other at ($P<0.05$).

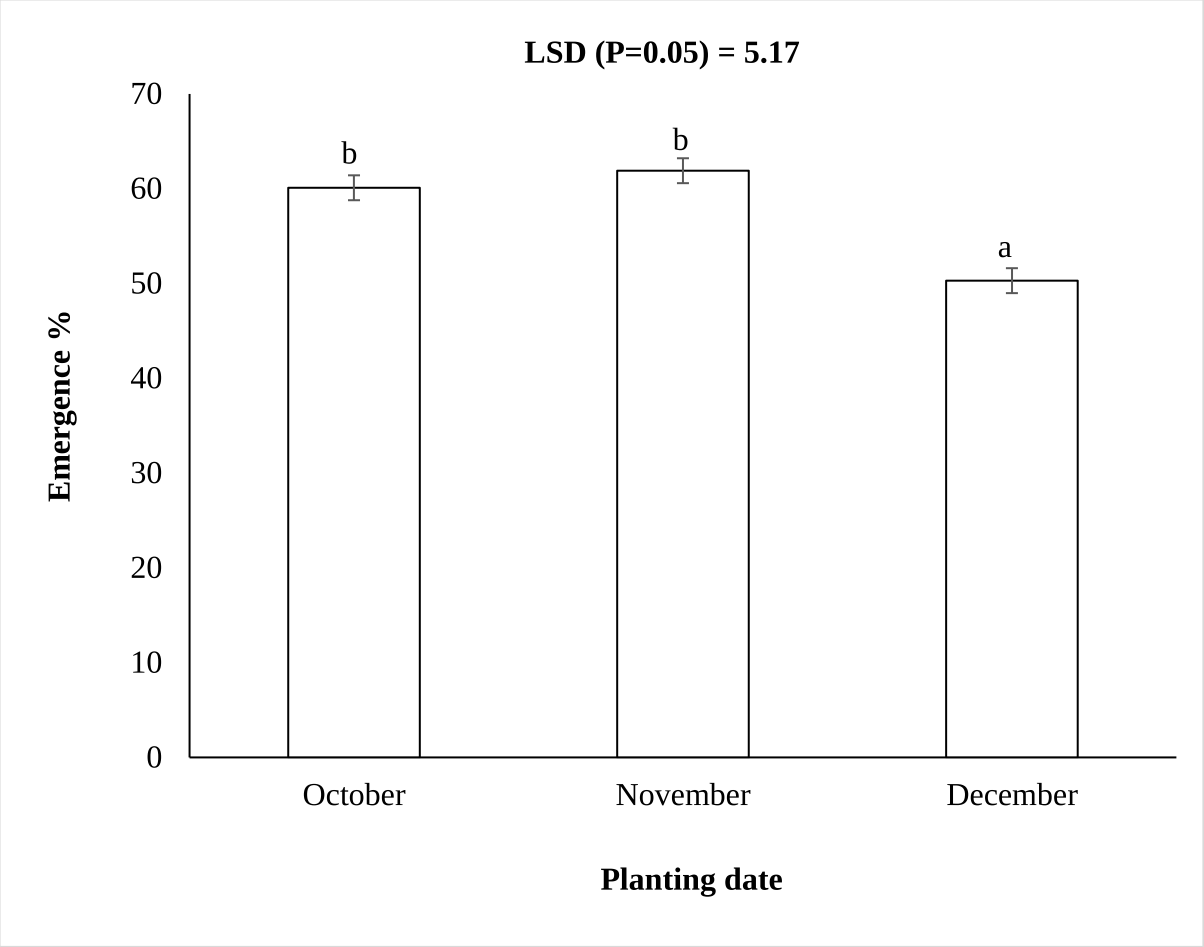

Figure 4.3: Effect of planting date averaged across landraces and Gromor Accelerator® application rate on emergence under dryland field conditions.

4.3.2 Leaf number

The planting date ($P = 0.025$) and fertiliser level ($P<0.001$) were observed to play a significant role in the number of leaves plant^{-1}. Results showed no significant differences ($P<0.05$) for taro landraces planted at three planting dates at Ukulinga with respect to leaf number plant^{-1}. However, Gromor Accelerator® application rate, landraces, and their interactions with planting dates were also observed to have no effect on the number of leaves plant^{-1} over time ($P>0.05$). Results indicated the early planting date October with a significantly higher number of leaves per plant than one and two months' delay planting dates who had the same number of leaves per plant where all planting dates were not different from each other (Figure 4.4). Therefore, delaying planting by one month and two months resulted to a reduction in the number of leaves plant^{-1} from 3.624 to 3.449, with a similar reduction rate in the number of leaves for November and December planting dates both averaged at 3.449 (Figure 4.4). The application of fertiliser did enhance the leaf number plant^{-1}, as 0 N kg per hectare of organic fertiliser obtained the lowest leaf number plant^{-1} (3.320) followed by 160 N kg per hectare of organic fertiliser (3.560). In contrast, a further increase in organic fertiliser resulted in the highest (3.642) leaf number plant^{-1} with 320 N kg per hectare of organic fertiliser, but organic fertiliser of 160 and 320 N kg per hectare displayed not to be different (Figure 4.5).

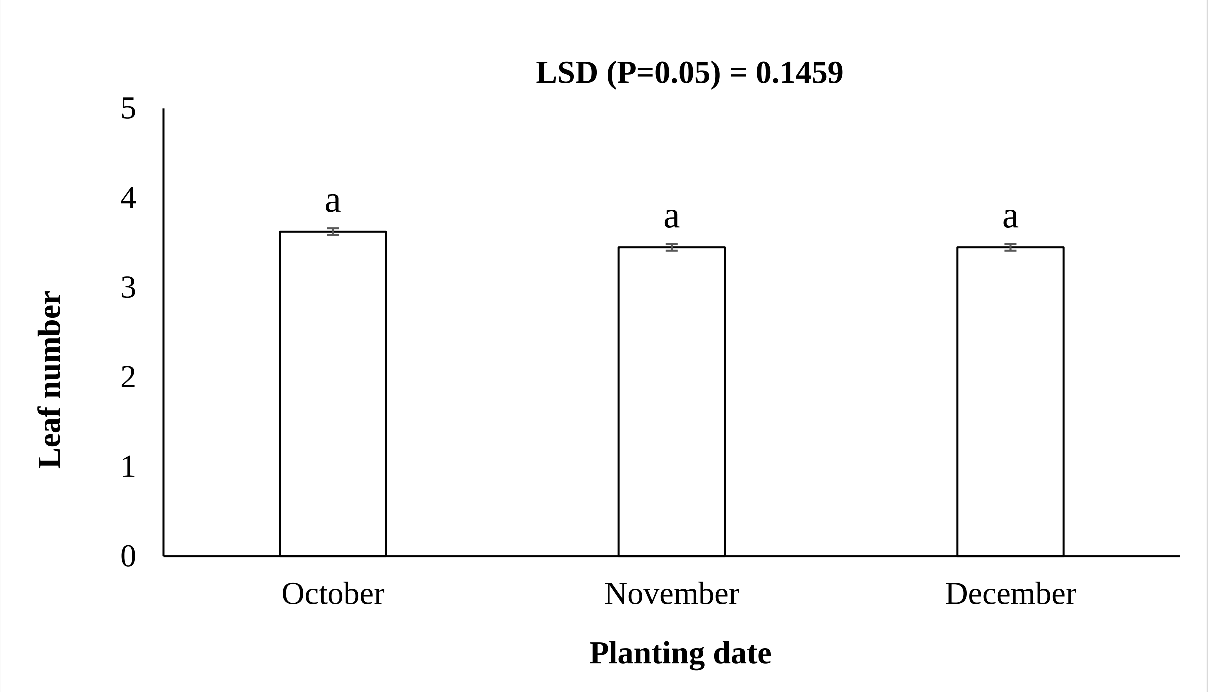

Figure 4.4: Effect of planting date averaged across landraces and Gromor Accelerator® application rate on number of leaves per plant under dryland field conditions.

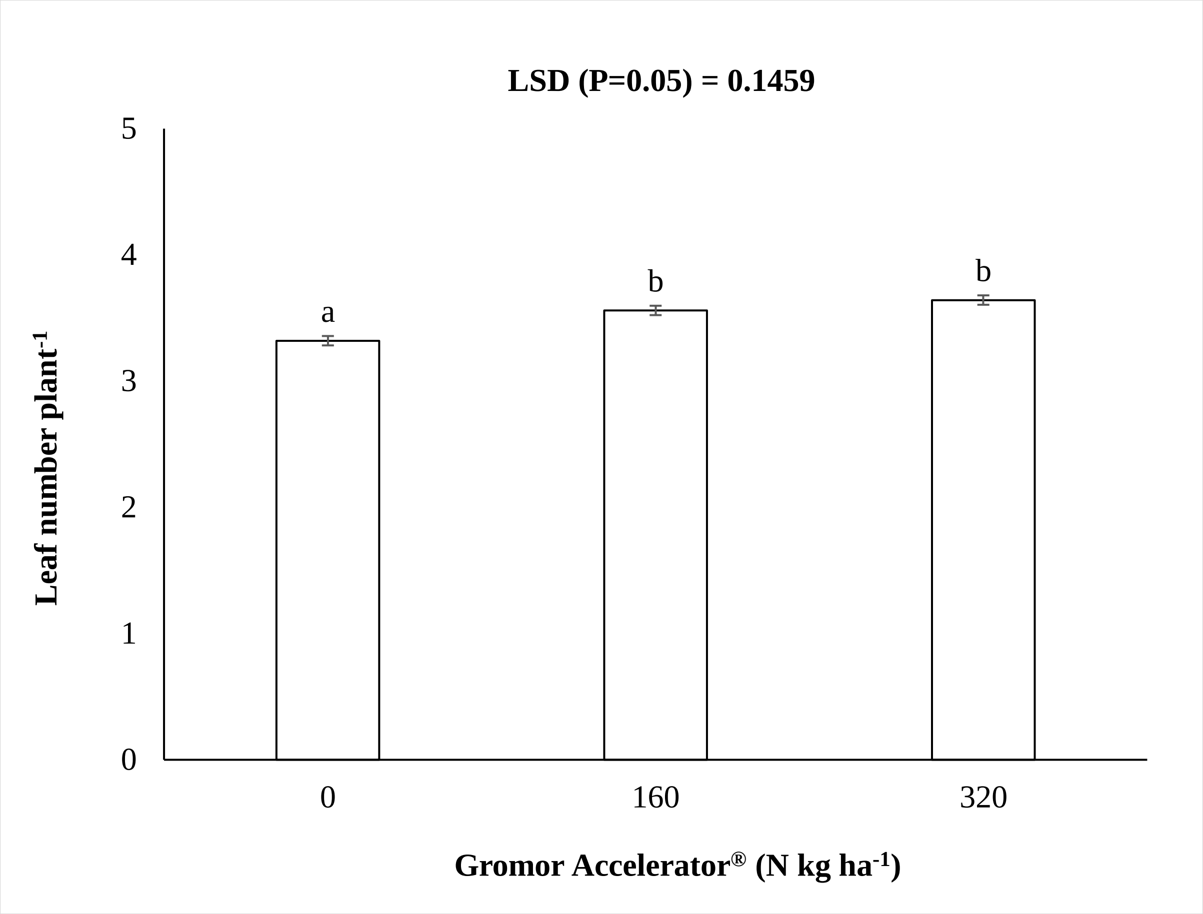

Figure 4.5: Effect of Gromor Accelerator® application rate averaged across planting date and landraces on number of leaves per plant under dryland field conditions.

4.3.3 Plant height

Results for planting date ($P<0.001$), landraces ($P = 0.002$), and Gromor Accelerator® application rate ($P<0.001$) showed to be highly significant over time. This is an indication that the application of organic fertiliser as well as the effect of planting date, enhanced the plant height of MG and PI. All the interactions of planting date, landraces, and Gromor Accelerator® application rate was not significant ($P>0.05$). Mean values indicated October planting (42.43 cm) as having the highest plant height, followed November (30.30 cm), which was significantly higher than two months delay in planting December (29.98 cm) (Figure 4.6). Application of organic fertiliser had an effect on plant height, where the 320 N kg per hectare of organic fertiliser had higher plant height followed by low organic fertiliser level 160 N kg per hectare and the no fertiliser level obtaining the lowest plant height over time (Figure 4.7). Plant height of taro landraces was negatively affected by delaying planting date and fertiliser application, where MG showed higher plant height than PI over time (Figure 4.8). A similar pattern was observed with leaf number, where delaying planting and applying organic fertiliser influenced the leaf number of taro landraces.

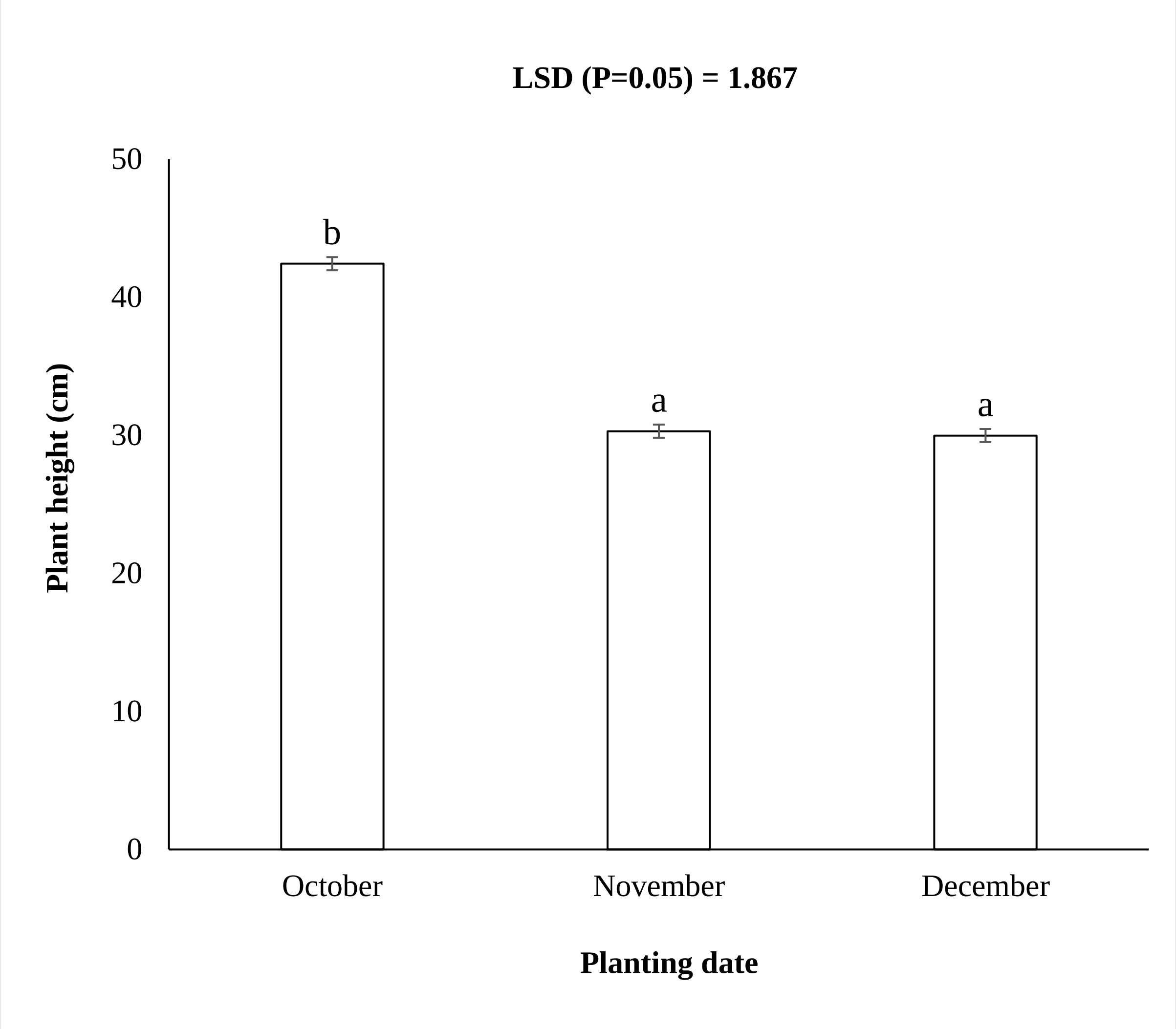

Figure 4.6: Effect of planting date averaged across landraces and Gromor Accelerator® application rate on plant height plant under dryland field conditions.

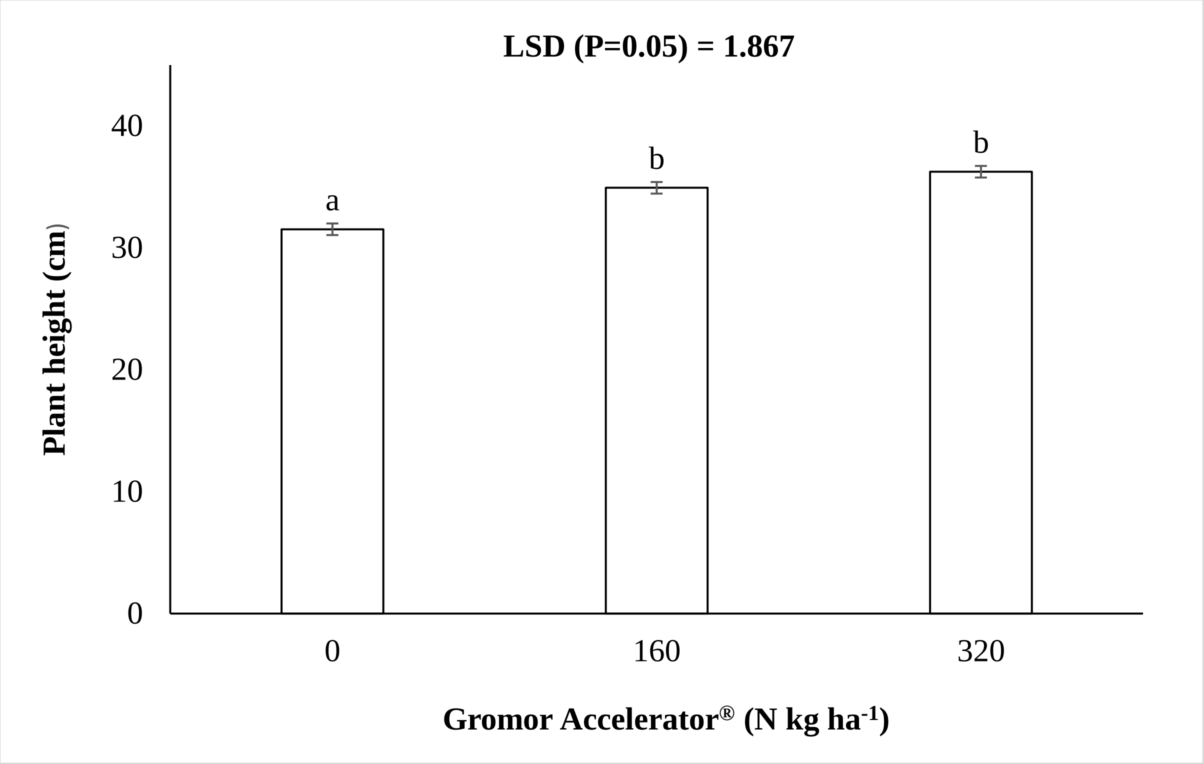

Figure 4.7: Effect of Gromor Accelerator® application rate averaged across planting date and landraces on plant height under dryland field conditions.

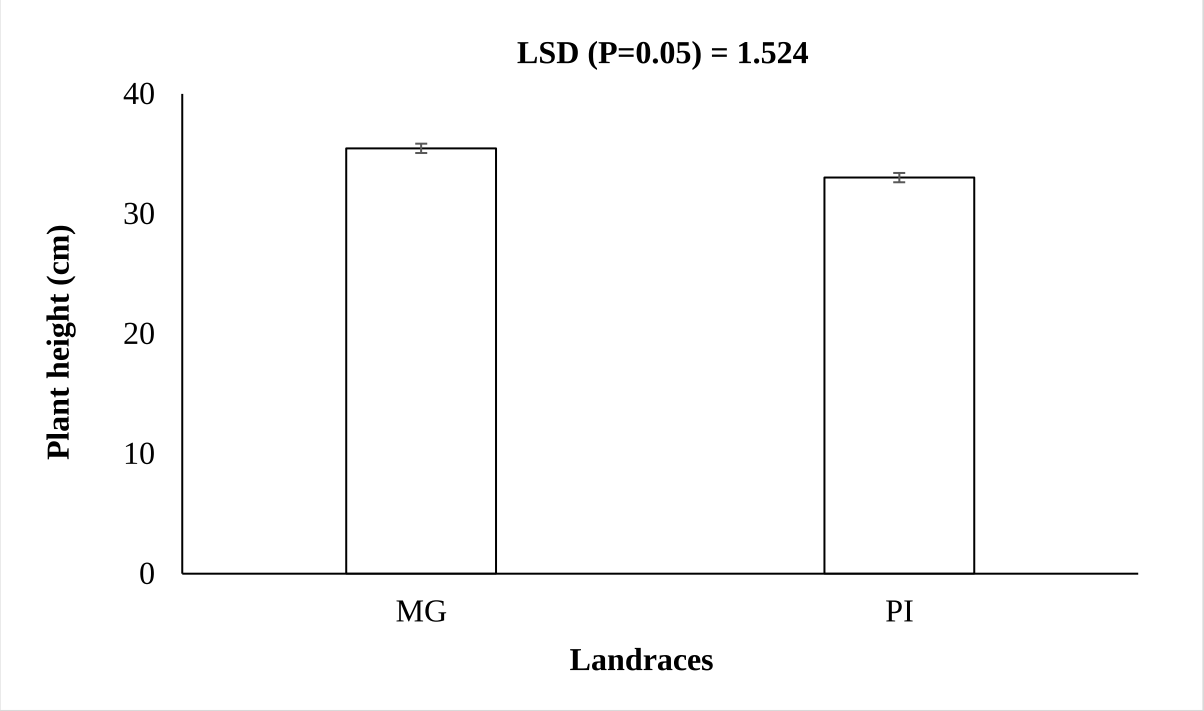

Figure 4.8: Effect of landraces averaged across planting date and Gromor Accelerator® application rate on plant height under dryland field conditions.

4.3.4 Leaf area

Results on leaf area plant^{-1} at Ukulinga was significantly affected by planting date ($P<0.001$), landraces ($P = 0.004$), Gromor Accelerator® application rate ($P<0.001$) as well as the interaction of planting date and Gromor Accelerator® application rate ($P<0.001$) over time. There was a higher increase in leaf area plant^{-1} for MG (502.6 cm^2) than PI (453.1 cm^2) over time (Figure 4.9).

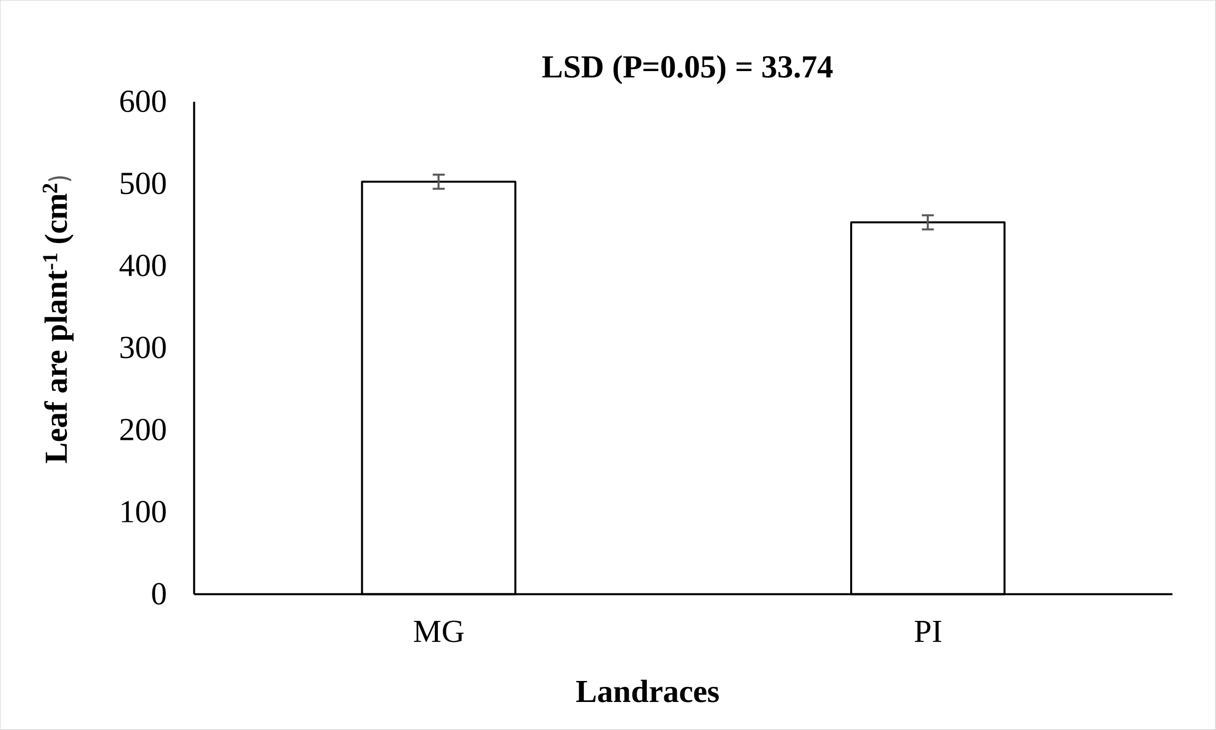

Figure 4.9: Effect of landraces averaged across planting date and Gromor Accelerator® application rate on leaf area per plant under dryland field conditions.

Organic fertiliser was observed to enhance more of leaf area per plant for early planting date, which significantly had a higher increase in leaf area per plant than the two late planting date November and December across all organic fertiliser application rates (Figure 4.10). When no organic fertiliser was applied, delaying planting by one month decreased leaf area plant^{-1} then followed by an increase in December. Results indicated an increase in leaf area per plant when planting was done in October and November when organic fertiliser of 160 or 320 N kg per hectare was applied, whereas in December leaf area plant^{-1} decreased with 160 N kg per hectare then increased with 320 N kg per hectare of organic fertiliser. Delaying planting from October to December significantly decreased the leaf area plant^{-1} of taro corms when 160 or 320 N kg per hectare of organic fertiliser was applied where the application rate of 320 N kg per hectare of organic fertiliser showed no difference between November and December. October obtained the highest leaf area per plant when 320 N kg per hectare of organic fertiliser was applied while the lowest was obtained by December planting with 160 N kg per hectare of organic fertiliser.

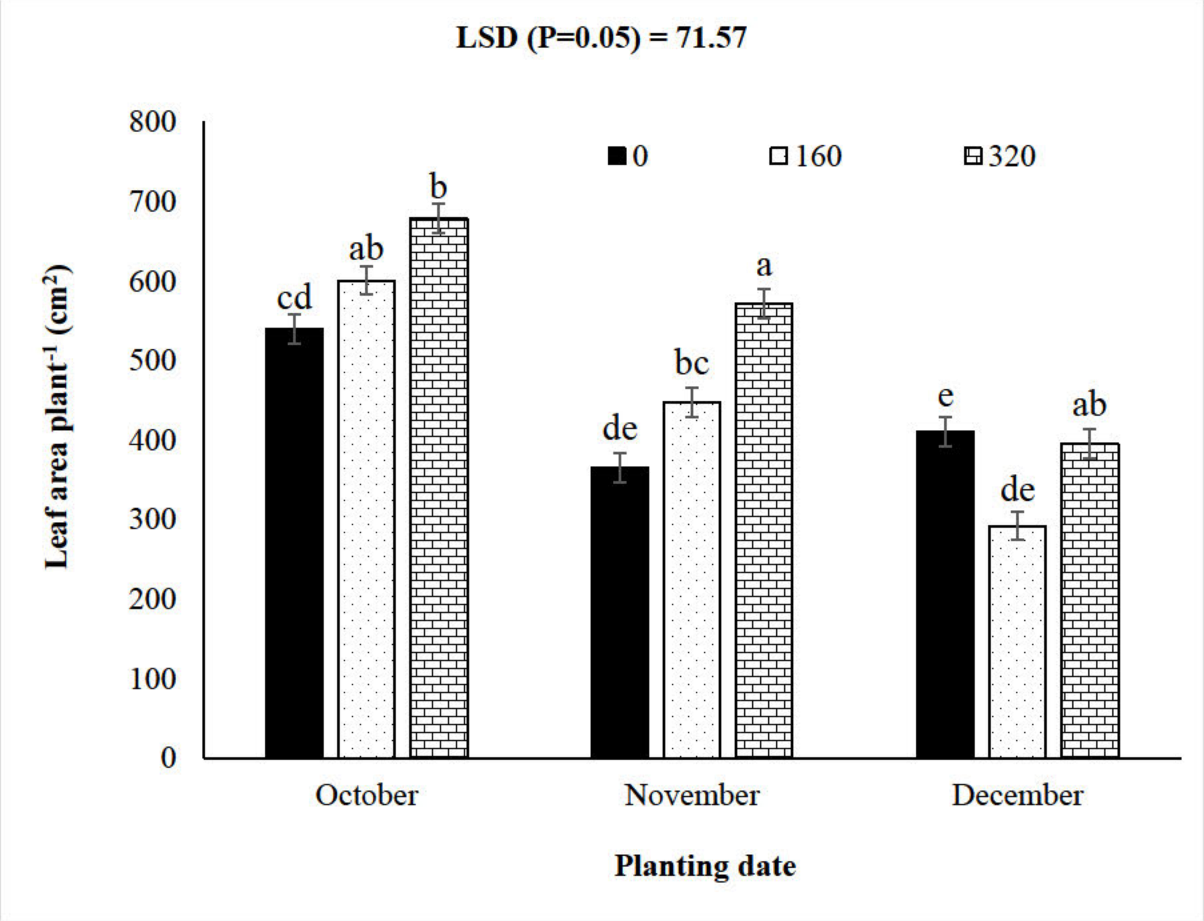

Figure 4.10: Effect of planting date and Gromor Accelerator® application rate (0, 160 and 320 N kg ha^{-1}) averaged across landraces on leaf area plant^{-1} under dryland field conditions.

4.3.5 Chlorophyll content index

Results showed that the planting date differed significantly ($P<0.001$) with respect to CCI. Landraces and Gromor Accelerator® application rate, including all the interactions of planting date, landraces, and Gromor Accelerator® application rates were observed not to play a significant role ($P>0.05$). Delaying planting by one month from October showed a significant increase in CCI, while a further delay by two months showed a decrease in CCI where October and November were not significantly different (Figure 4.11). November planting date (50.45) had the highest CCI followed by early planting date October (48.86), then lastly, the two months delay in planting date December (45.93).

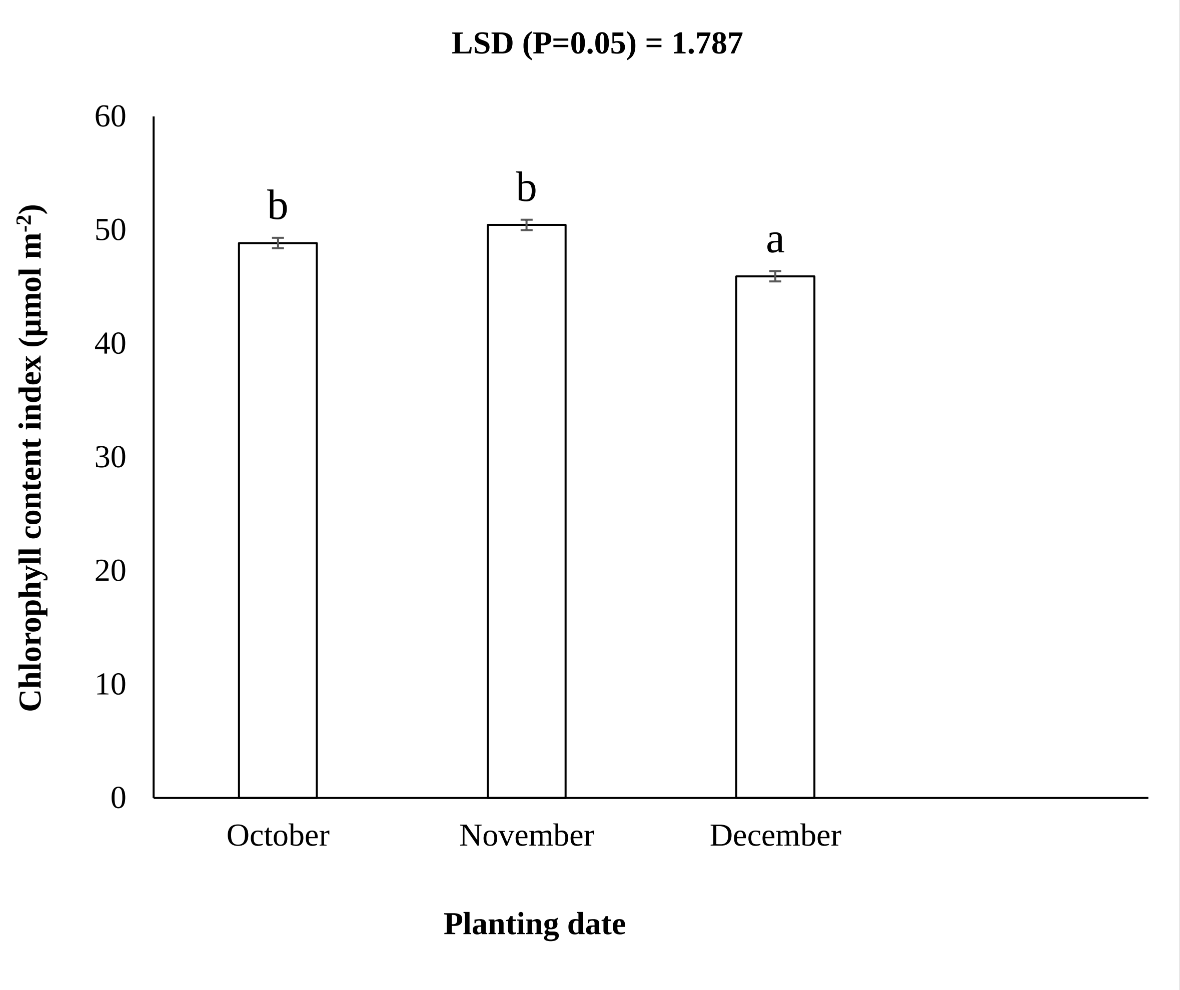

Figure 4.11: Effect of planting date averaged across landraces and Gromor Accelerator® application rate on chlorophyll content index at dryland field conditions.

4.3.6 Photosynthetic active radiation

Results showed that the planting date had a significant effect ($P<0.001$) with respect to PAR. There was no significant effect observed on landraces, Gromor Accelerator® application rate, and all the interactions of planting date, landraces and fertiliser level ($P>0.05$). Maximum PAR was recorded from late November planting from both PAR above and below (Figure 4.12 and 4.13), followed by December and October planting respectively but, significant variation for PAR above was not observed among the late two planting dates November and December.

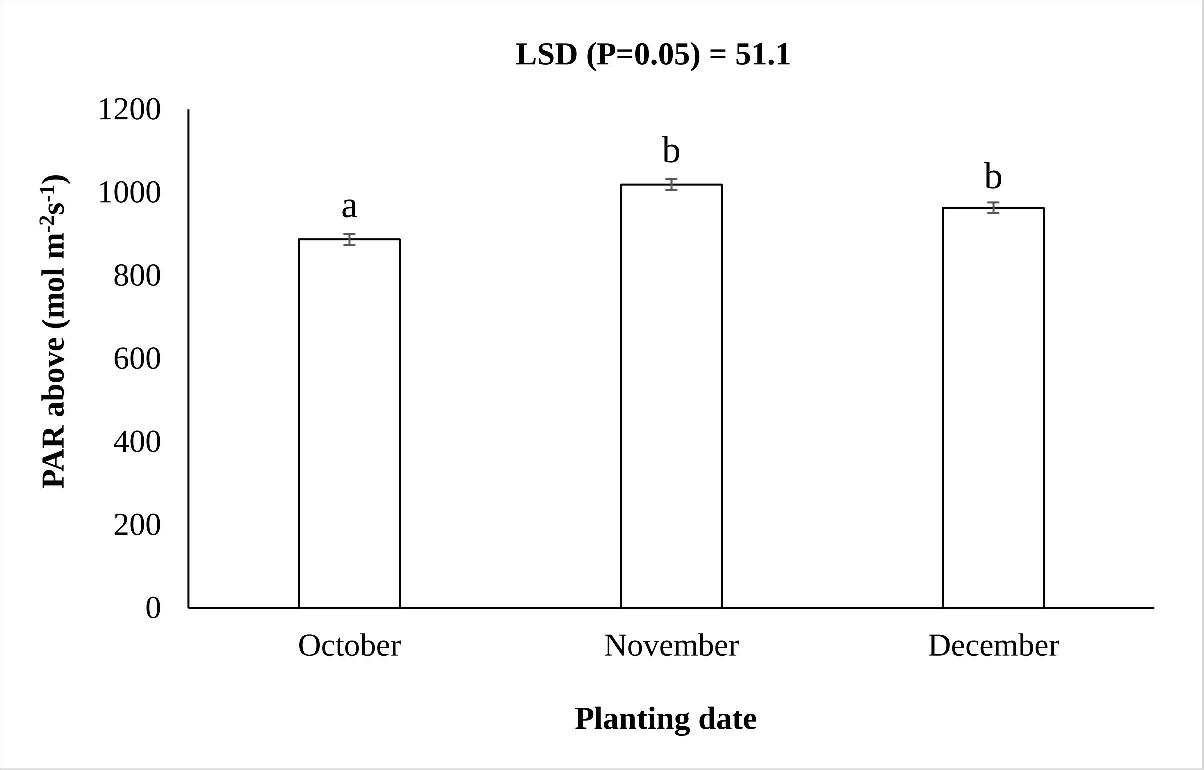

Figure 4.12: Effect of planting date averaged across landraces and Gromor Accelerator® application rate on photosynthesis active radiation above under dryland field condtions.

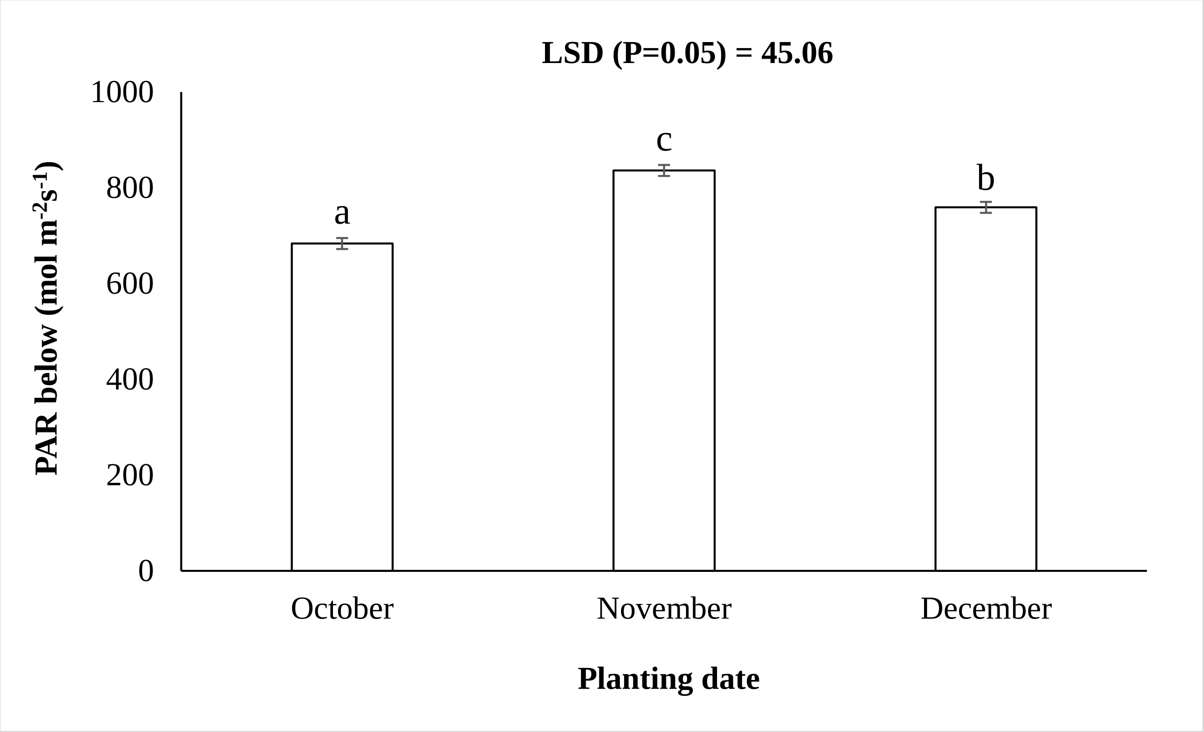

Figure 4.13: Effect of planting date averaged across landraces and Gromor Accelerator® application rate on photosynthesis active radiation below under dryland field conditions.

4.3.7 Stomatal conductivity

A significant effect was observed from the landraces (P = 0.005) and Gromor Accelerator® application rate (P = 0.004) on the SC of taro over time, however, the planting date, as well as all of the interactions, were observed not significant (P>0.05). Results of SC showed that sensitivity of stomatal closure to the application of organic fertiliser was landrace dependent, with PI being the most sensitive than MG (Figure 5.14). MG (79.4 mmol m^{-2} s^{-1}) yielded the highest SC than PI (73.1 mmol m^{-2} s^{-1}) over the growing period. For Gromor Accelerator® application rate stomatal closure was more sensitive on 0 N kg ha^{-1}, followed by 160 N kg per hectare with 320 N kg per hectare of organic fertiliser yielding the highest stomatal conductivity than all organic fertiliser application rates where applying 160 and 320 N kg per hectare of organic fertiliser showed no differences (Figure 5.15).

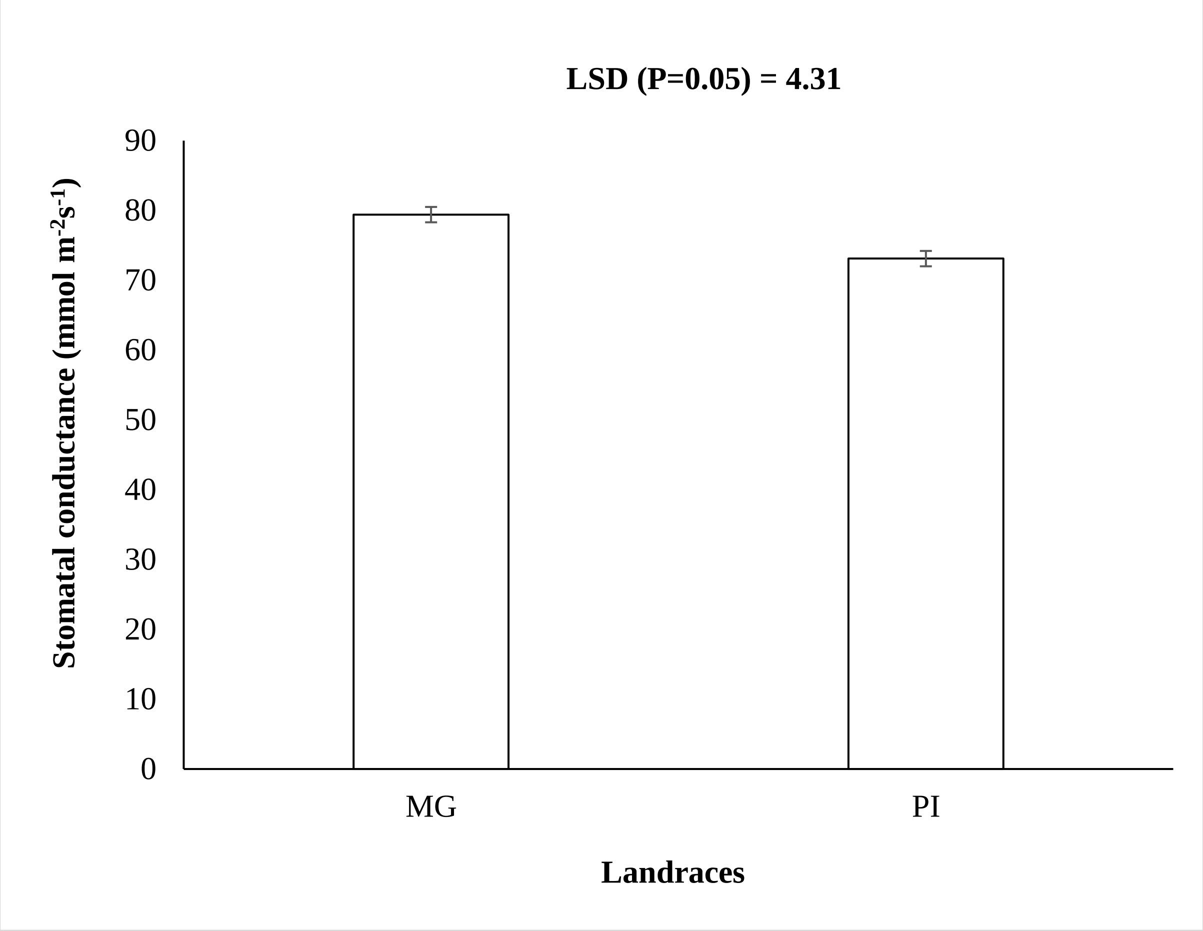

Figure 4.14: Effect of landraces averaged across planting date and Gromor Accelerator® application rate on stomatal conductance under dryland field conditions.

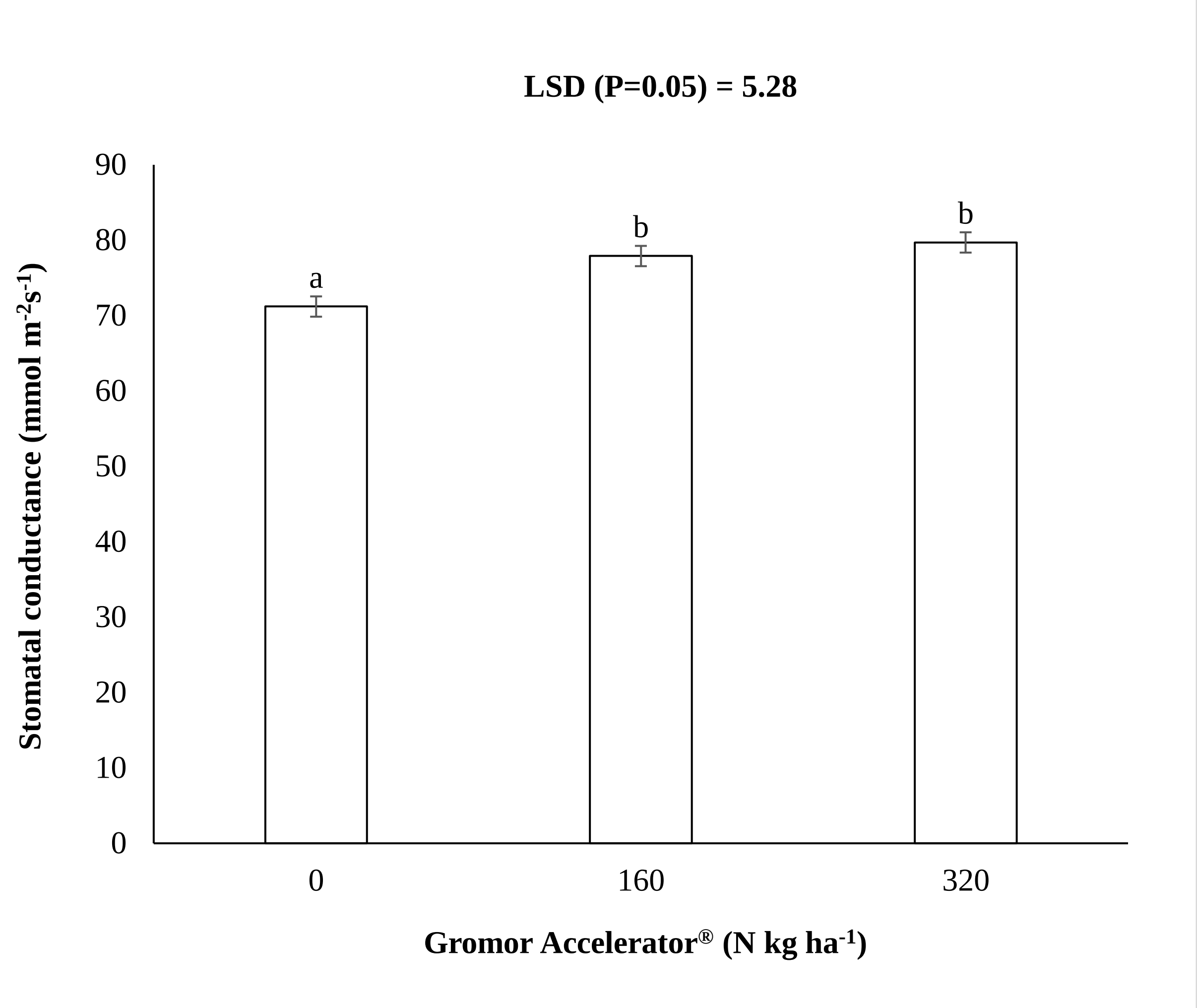

Figure 4.15: Effect of Gromor Accelerator® application rate averaged across planting date and landraces on stomatal conductance under dryland field conditions.

4.3.8 Soil water content

Results of soil water content varied significantly ($P<0.001$) with regards to the planting date. The landraces, fertiliser level as well as all the interactions of planting date, landraces and fertiliser level were observed not significant ($P>0.05$). October planting was found with the highest (27.67%) SWC followed by one-month delay (24.53%), and two months delay (21.81%) in planting dates (Figure 4.16). This could be an indication that rising temperatures had an effect on SWC overtime at Ukulinga. The planting dates were observed to be significant to each other for SWC. The rain gauge indicated a high amount of rainfall during the early planting date, and then it decreased towards the late planting date (Figure 4.17).

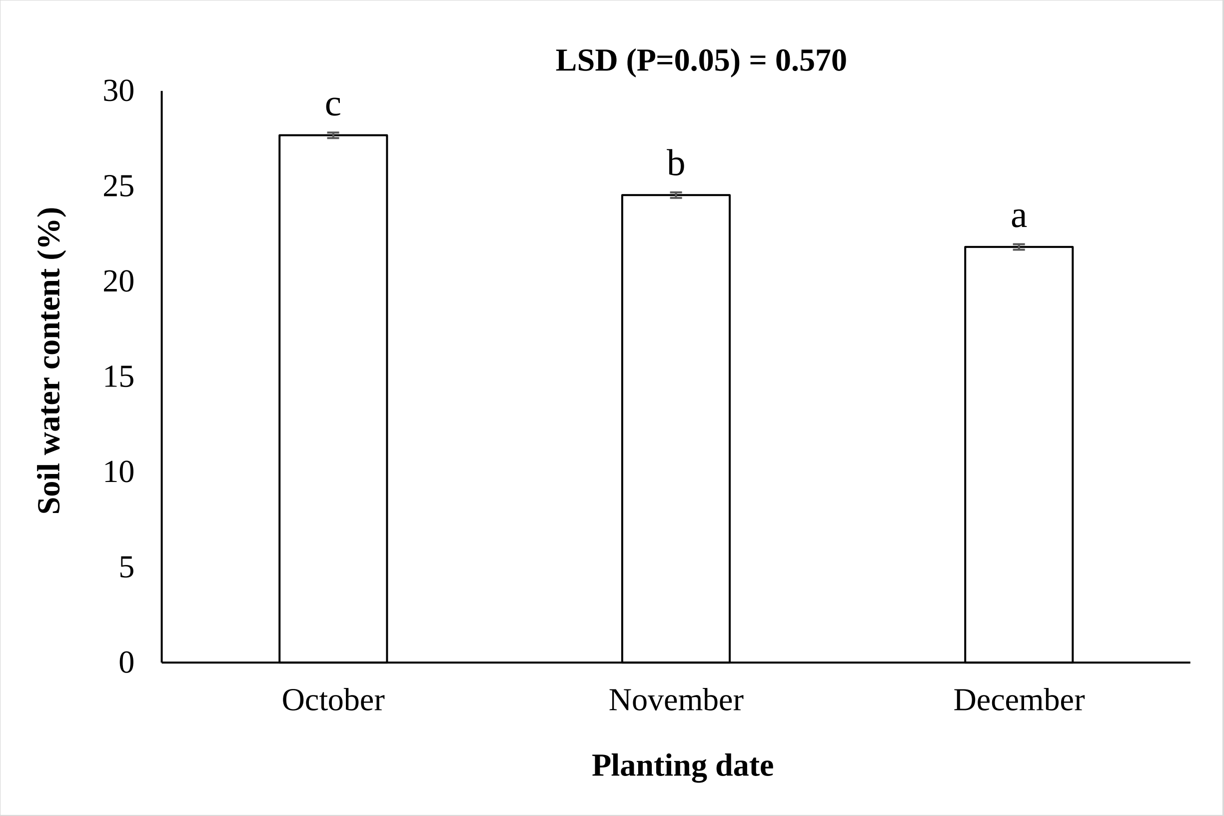

Figure 4.16: Effect of planting date averaged across landraces and Gromor Accelerator® application rate on soil water content under dryland field conditions.

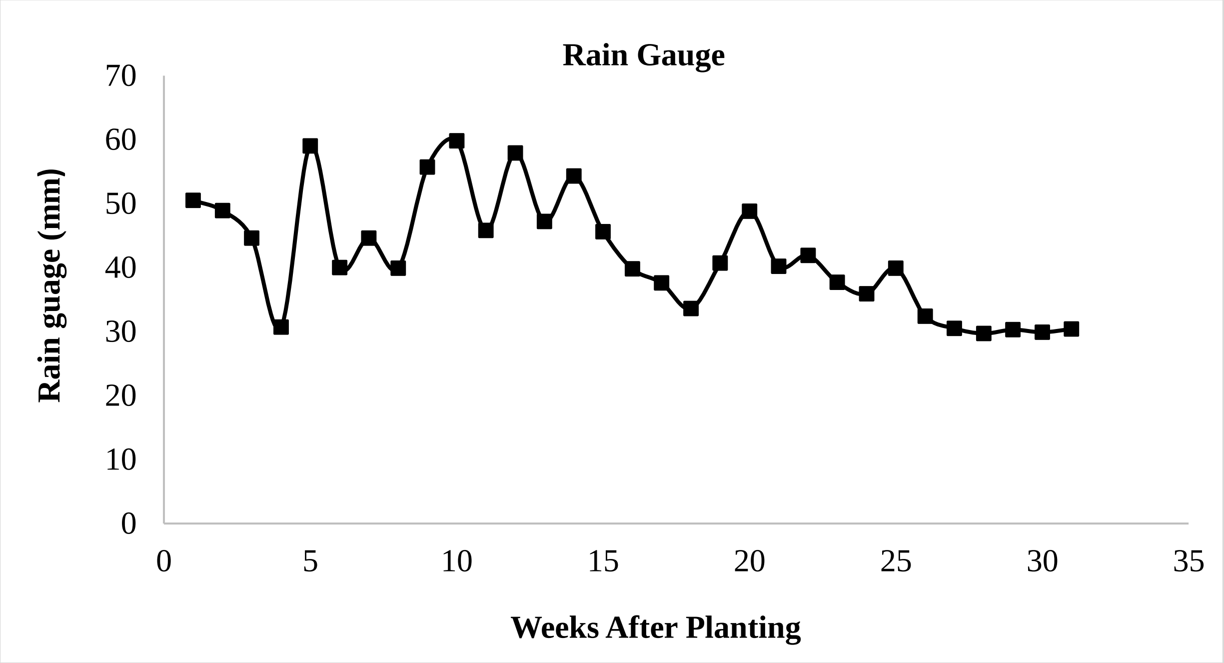

Figure 4.17: Rain gauge (mm) during the growing period 2018/2019 for the field experiment under dryland field conditions.

4.3.9 Yield and yield parameters

4.3.9.1 Plant biomass

Results recorded for biomass per plant kg showed that planting date, landraces, Gromor Accelerator® application rate, the interaction of planting date and landraces as well as planting date and Gromor Accelerator® application rate played a significant role ($P<0.001$). However, the interaction of landraces and Gromor Accelerator® application rate and the interaction of planting date, landraces and Gromor Accelerator® application rate was not significant ($P>0.05$). Biomass per plant kg of taro landraces was negatively affected by delayed planting at Ukulinga (Figure 4.18). Early planting (October) showed greater biomass per plant kg as compared to one month and two months delay in planting with MG obtaining higher biomass per plant kg than PI. However, delaying planting by one and two months showed PI with higher biomass per plant kg than MG, where November and December planting showed no difference in biomass per plant kg between landraces.

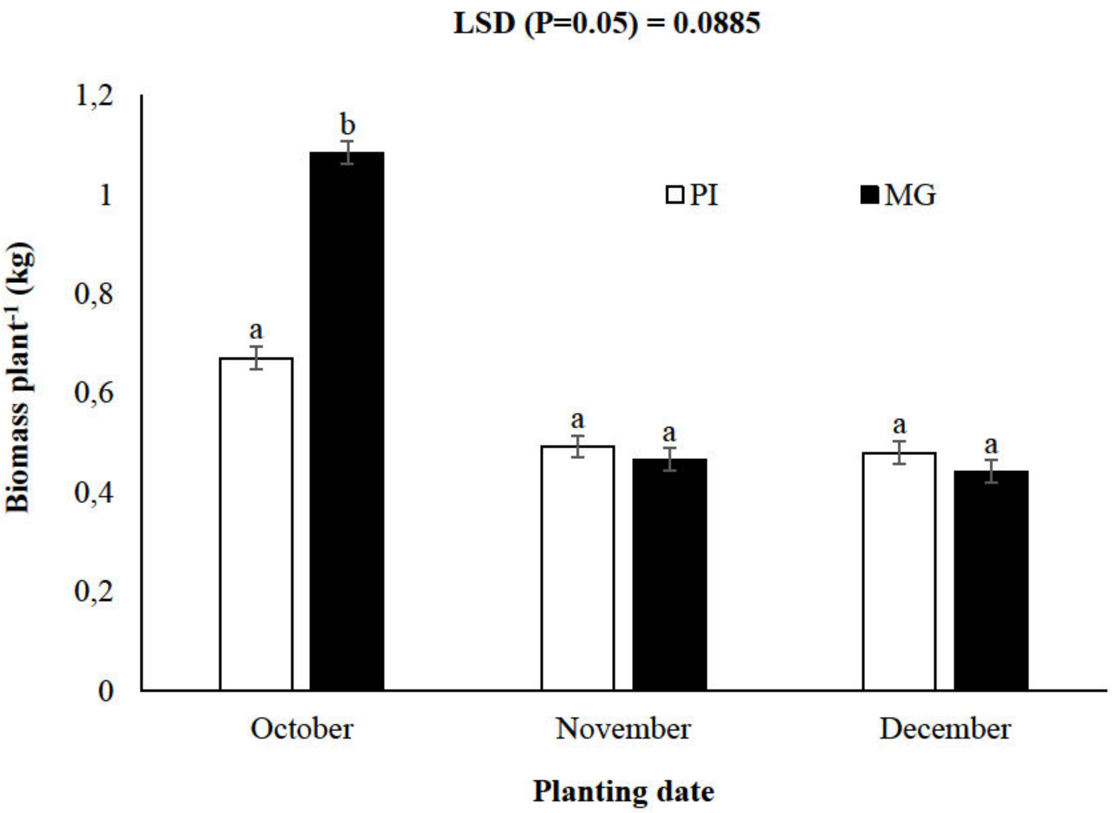

Figure 4.18: Effect of planting date and landraces (PI and MG) averaged across Gromor Accelerator® application rate on taro biomass under dryland field conditions.

Delaying planting by one and two month's significantly decreased biomass per plant kg when organic fertiliser was applied. Application of 160 N kg per hectare of organic fertiliser enhanced biomass per plant kg for October planting and was higher than December and November, respectively (Figure 4.19). However, adding more organic fertiliser of 320 N kg per hectare significantly did not improve biomass per plant kg when planting was delayed by one and two months, with October obtaining higher biomass per plant kg followed by November and December. Whereas when fertiliser was not applied, the lowest biomass per plant kg was only observed with two months delay in planting, and October obtaining high biomass per plant kg followed by November planting. The application of organic fertiliser only enhanced the biomass per plant kg for October planting, compared to November and December planting, where application rate of 160 and 320 N kg per hectare of organic fertiliser was not different in October.

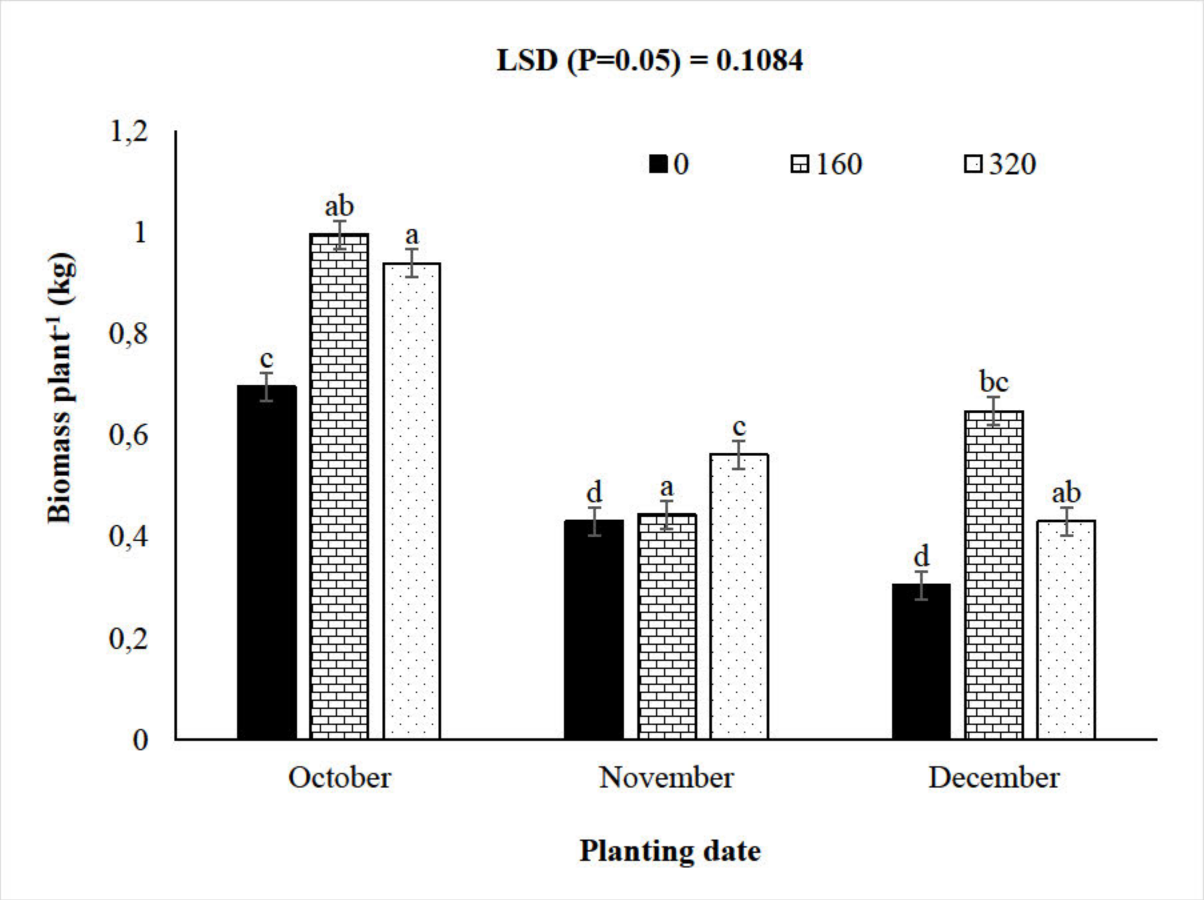

Figure 4.19: Effect of planting date and Gromor Accelerator® application rate (0, 160 and 320 N kg ha^{-1}) averaged across landraces on taro biomass under dryland field conditions.

4.3.9.2 Corm mass per plant

A highly significance difference ($P<0.001$) on corm mass plant^{-1} kg was observed with planting date, landraces, Gromor Accelerator® application rate, including the interaction between planting date and landraces, and planting date and Gromor Accelerator® application rate. Planting date significantly affected the landraces corm mass per plant kg (Figure 4.20). For October, planting MG was observed with the highest corm mass per plant kg than PI; however, on average, October planting obtained higher corm mass per plant kg for both landraces relative to delayed planting dates November and December. The same trend was observed with November planting, where higher corm mass per plant kg was obtained by MG than PI, but with two months delay in planting PI received higher corm mass per plant kg than MG. Delayed planting November and December were not different with respect to corm mass per plant kg between landraces.

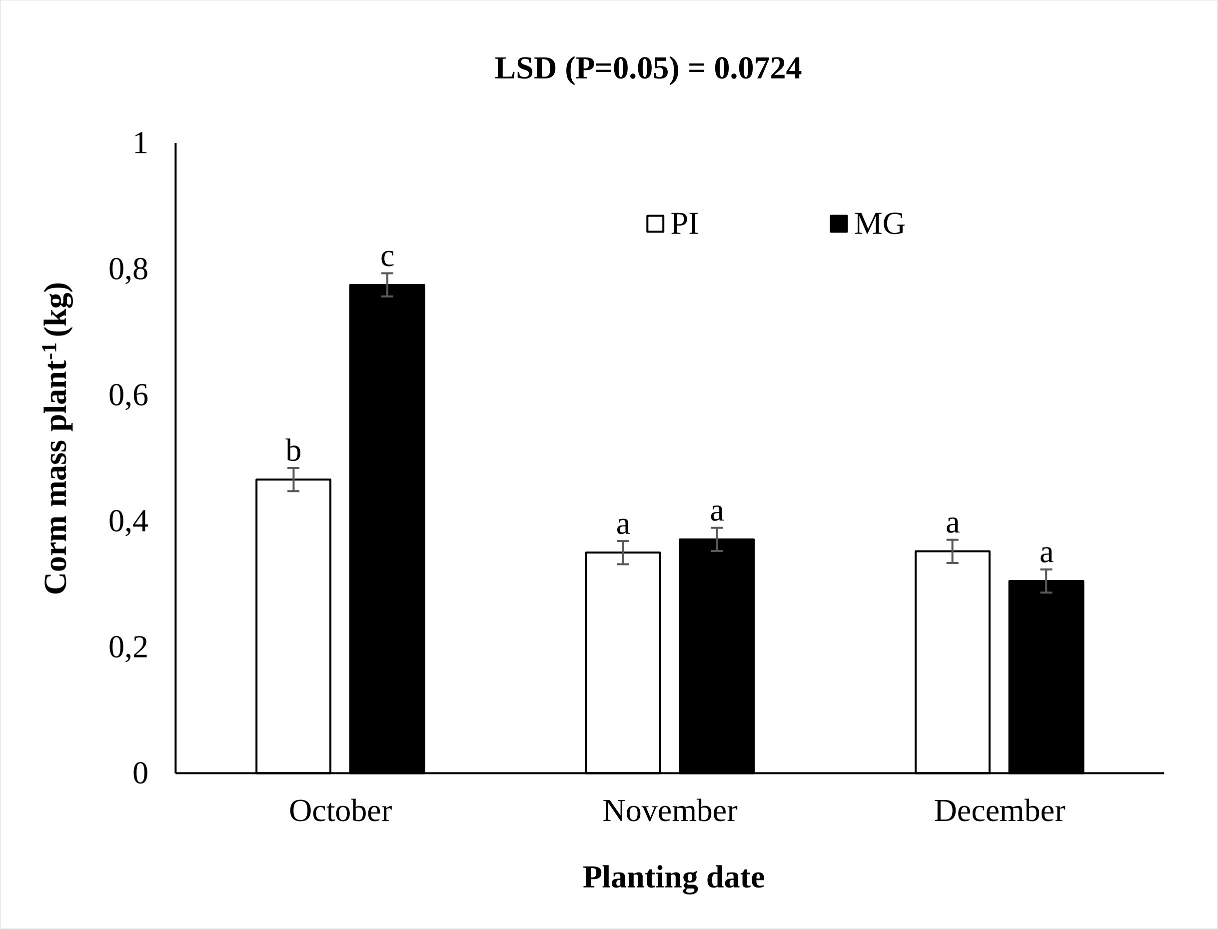

Figure 4.20: Effect of planting date and landraces (PI and MG) averaged across Gromor Accelerator® application rate on taro corm mass under dryland field conditions.

Delaying planting by one and two months decreased corm mass per plant kg when organic fertiliser was applied, where the application of 160 N kg per hectare of organic fertiliser only enhanced October planting, achieving the highest corm mass per plant kg compared to other fertiliser levels and planting dates (Figure 4.21). However, adding more organic fertiliser of 320 N kg per hectare significantly did not improve corm mass per plant kg when planting was delayed by one and two months, even with early planting date. Whereas when fertiliser was not applied, a major decrease was only observed with December planting compared to October and November planting. There was no difference in corm mass plant^{-1} kg between October and November planting when 160 N kg per hectare of organic fertiliser was applied.

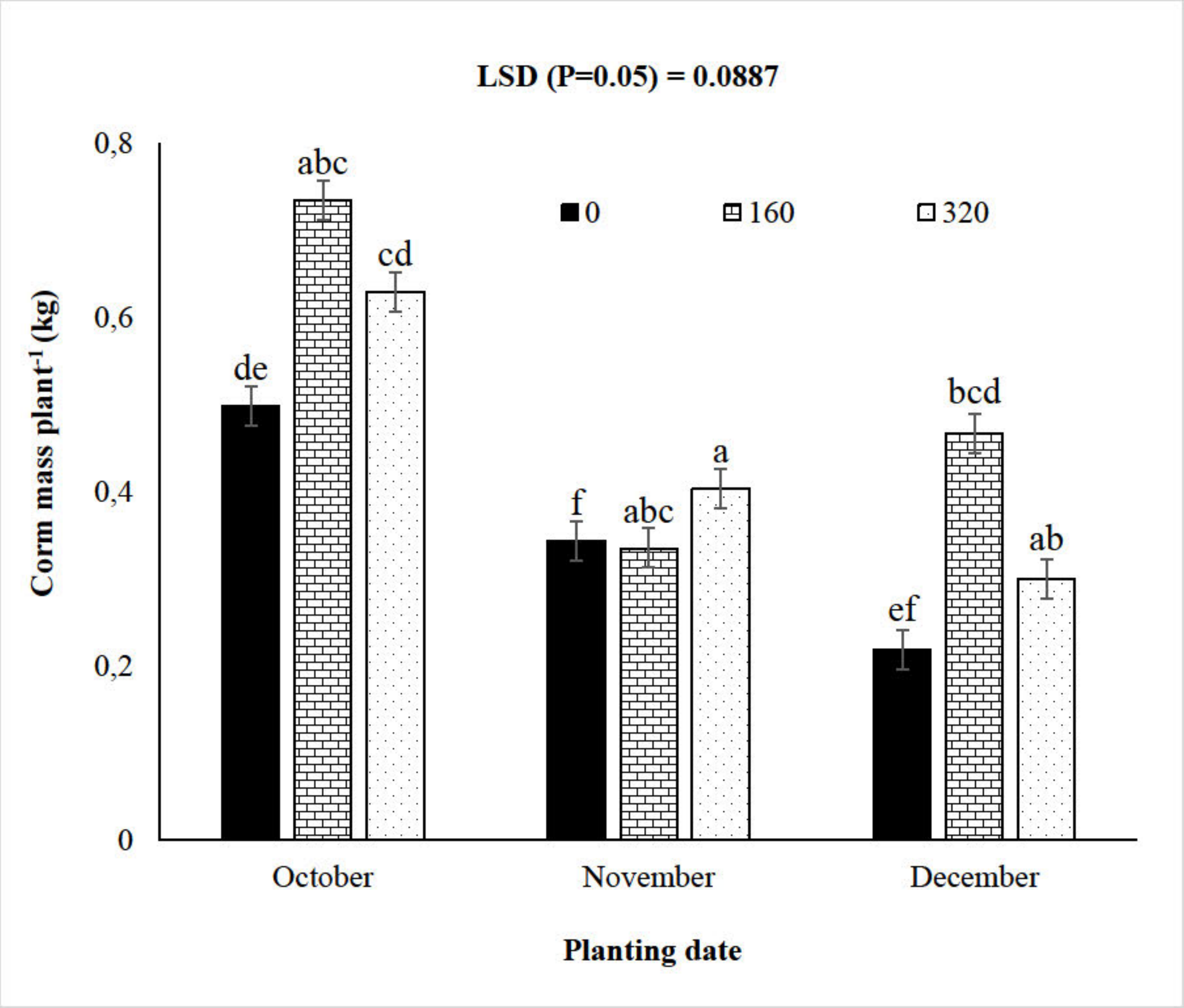

Figure 4.21: Effect of planting date and Gromor Accelerator® application rate (0, 160 and 320 N kg ha^{-1}) averaged across landraces on taro corm mass under dryland field conditions.

4.3.9.3 Number of cormels per plant

The number of cormels per plant was significantly affected by planting date, landraces, Gromor Accelerator® application rate, the interaction of planting date and landraces ($P<0.001$), and planting date and Gromor Accelerator® application rate ($P = 0.002$). PI obtained the fewest number of cormels per plant for October, November and December plantings (Figure 4.21). Overall, MG had the highest number of cormels per plant for all planting dates October, November and December. Delaying planting date by one and two months significantly decreased the number of cormels per plant for both MG and PI but, a severe decrease was more observed with the PI landrace (Figure 4.22). However, the same trend was observed that delaying planting led to a decrease in biomass and corm mass per plant kg. There was no difference in the number of cormels per plant between the landraces when they were planted in November and December. Delaying planting by one and two months had no significant effect on the number of cormels per plant for both MG and PI

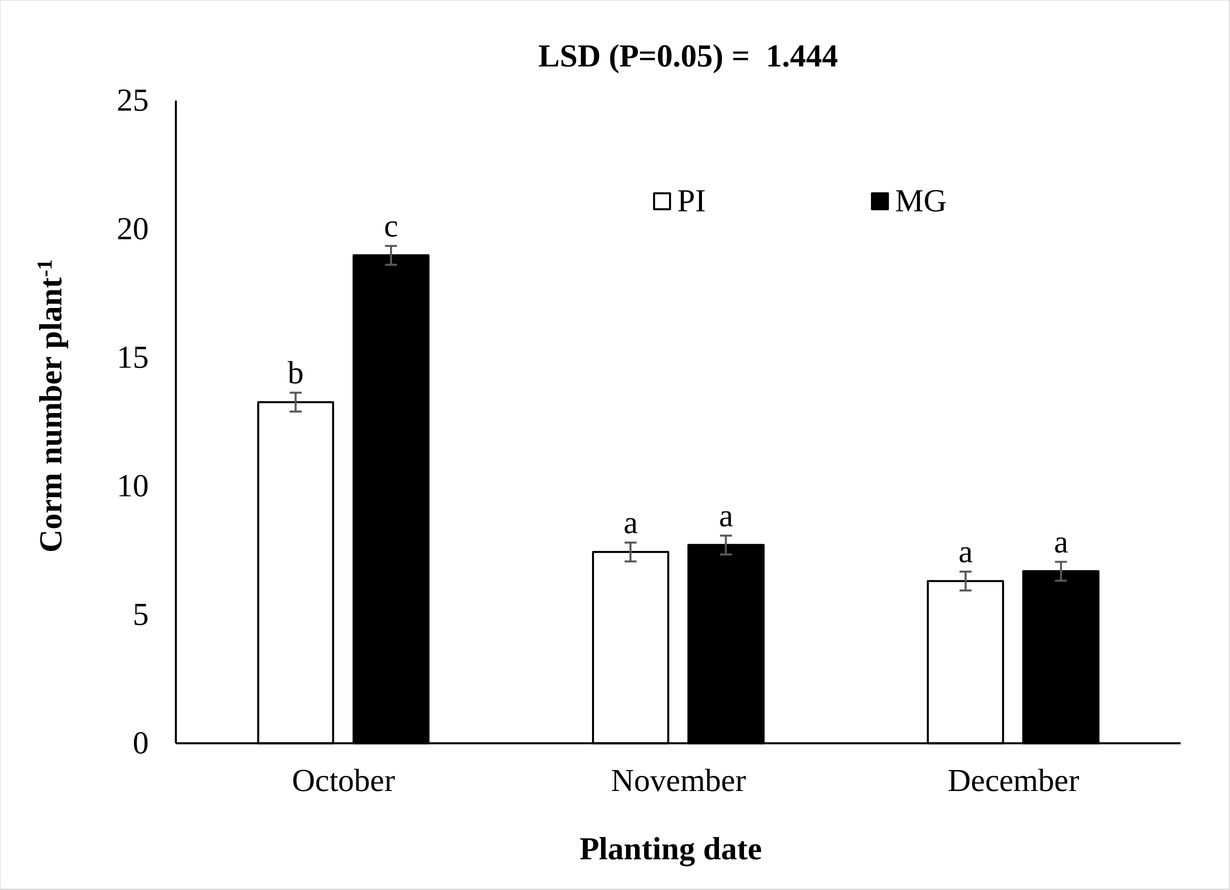

Figure 4.22: Effect of planting date and landraces (PI and MG) averaged across Gromor Accelerator® application rate on number of taro cormels under dryland field conditions.

Results indicated that delaying planting from October to December decreased the number of cormels per plant when 0, 160 and 320 N kg per hectare of organic fertiliser was applied (Figure 4.23). October planting significantly displayed the highest number of cormels per plant when 160, 320 and 0 N kg per hectare of organic fertiliser was applied respectively where the application rate of 160 and 320 N kg per hectare of organic fertiliser was not different. The highest number of cormels per plant was obtained with the application of 160 and 320 N kg per hectare in October, compared to November and December, even when the addition of 320 N kg per hectare was applied. This is an indication that organic fertiliser only enhanced the number of cormels per plant for October planting, where there was also no effect on the number of cormels per plant when planting was done in November and December.

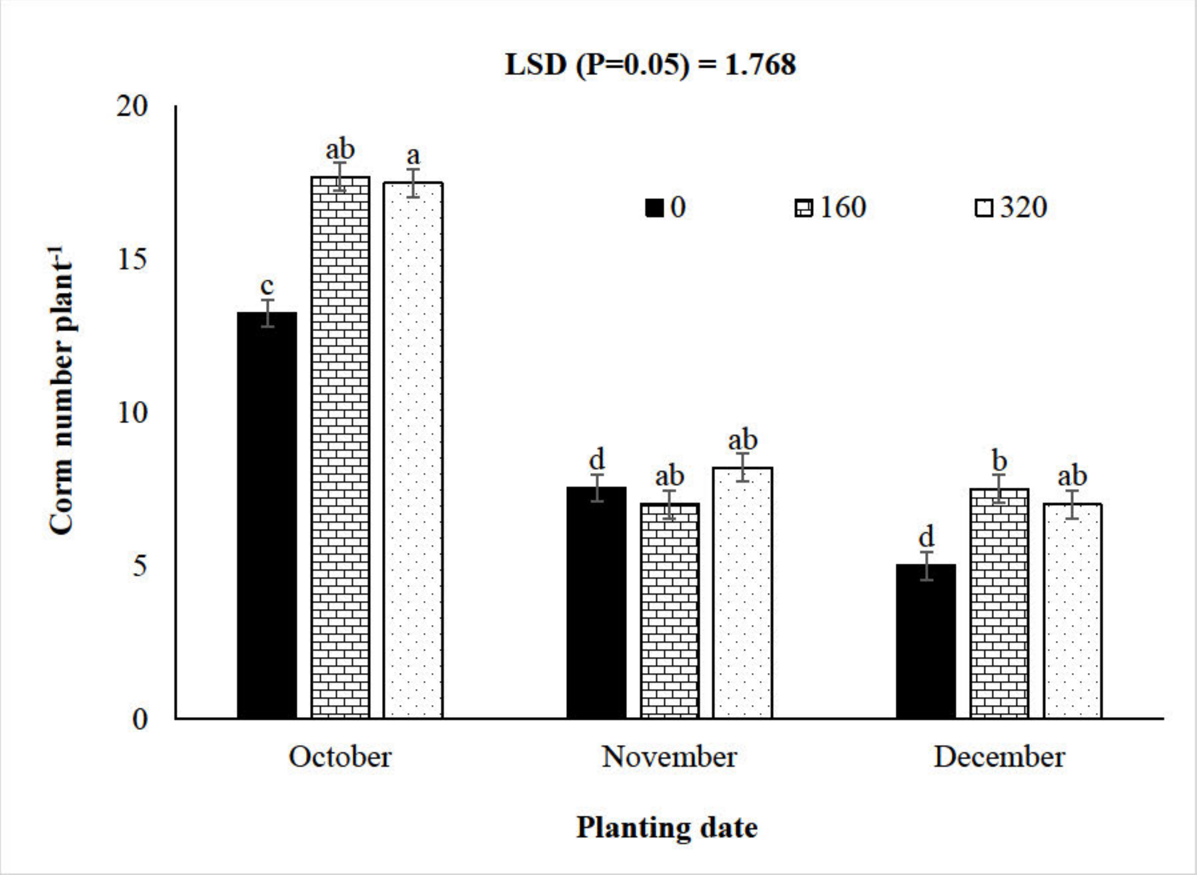

Figure 4.23: Effect of planting date and Gromor Accelerator® application rate (0, 160 and 320 N kg ha^{-1}) averaged across landraces on number of taro cormels under dryland field conditions.

4.3.9.4 Actual yield

The actual yield harvested was affected by planting date, landrace, Gromor Accelerator® application rate, the interaction of planting date and landrace, and the interaction of planting date and Gromor Accelerator® application rate were all observed to play a significant role at Ukulinga (P<0.001). There was no significant difference between the interaction of landrace and Gromor Accelerator® application rate and the interaction of planting date, landrace, and Gromor Accelerator® application rate with respect to the actual yield harvested (P>0.005). Results for actual yield kg per hectare showed that MG was higher during October and November planting compared to PI (Figure 4.24). But with December planting, PI obtained significantly higher actual yield kg per hectare than MG, where landraces planted in November and December were not different from each other. Overall, October yielded the highest actual yield kg per hectare compared to delayed planting dates, which showed a decrease in actual yield kg per hectare.

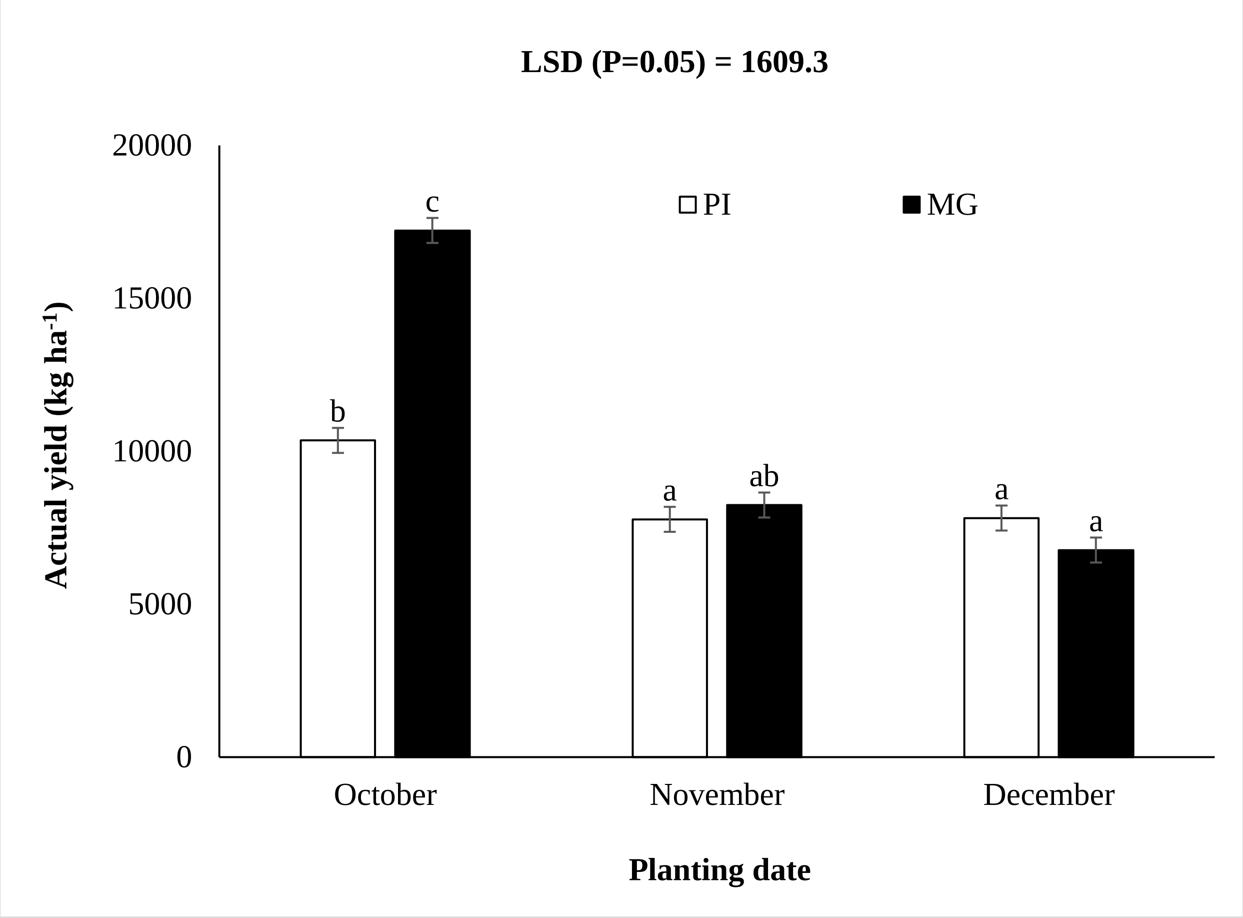

Figure 4.24: Effect of planting date and landraces (PI and MG) averaged across Gromor Accelerator® application rate on actual yield harvested of taro under dryland field conditions.

Results indicated that delaying planting dates by one month when no fertiliser was applied decreased the actual yield kg per hectare then followed by a small increase when planting was delayed until December (Figure 4.25). When 160 N kg per hectare of organic fertiliser was applied delaying planting from October to November, decreased actual yield kg per hectare then increased when planting was delayed by two months. Additional organic fertiliser of 320 N kg per hectare indicated a decrease in the actual yield kg per hectare when planting was delayed by one and two months. The highest actual yield kg per hectare was obtained by October planting with the application of 160 N kg per hectare of organic fertiliser where October and November showed no significant difference.

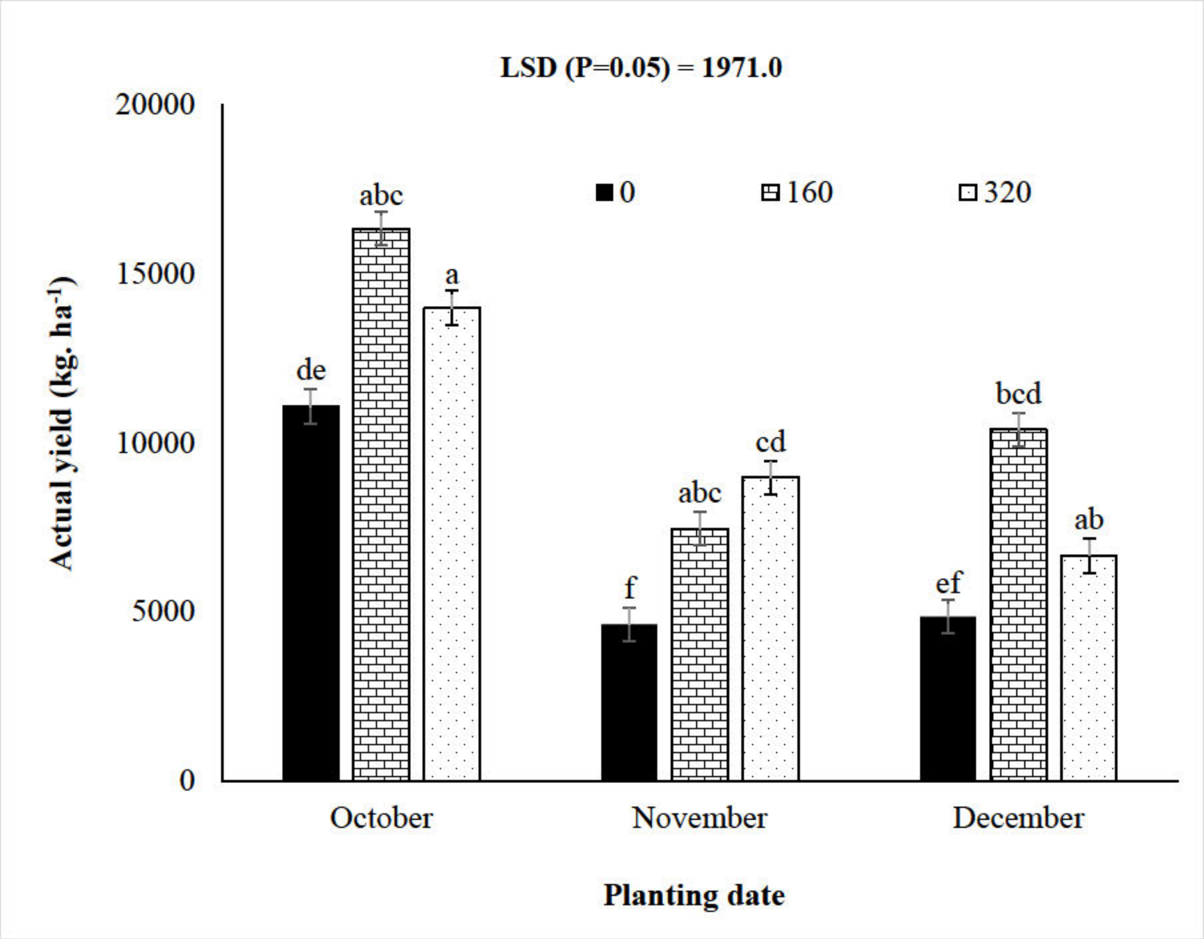

Figure 4.25: Effect of planting date and Gromor Accelerator® application rate (0, 160 and 320 N kg ha^{-1}) averaged across landraces on actual yield harvested of taro under dryland field conditions.

4.3.9.5 Harvest index

There were significant differences between the planting date (P = 0.001), Gromor accelerator application rate (P = 0.003), the interaction of planting date and landrace (P = 0.001), and the interaction of planting date, landrace, and Gromor accelerator application rate (P = 0.005). The landrace, interaction of planting date and Gromor accelerator application rate, and the interaction of landrace and Gromor accelerator application rate did not show any significant differences (P>0.005). Overall, the results indicated that MG had better HI for October and November planting compared to PI, where MG yielded the highest HI when planting was delayed until December planting (Figure 4.26). Whereas, two months delay in planting showed PI with significantly higher HI than MG, where there was no significantly different effect between landraces when planting was done in October, November and December.

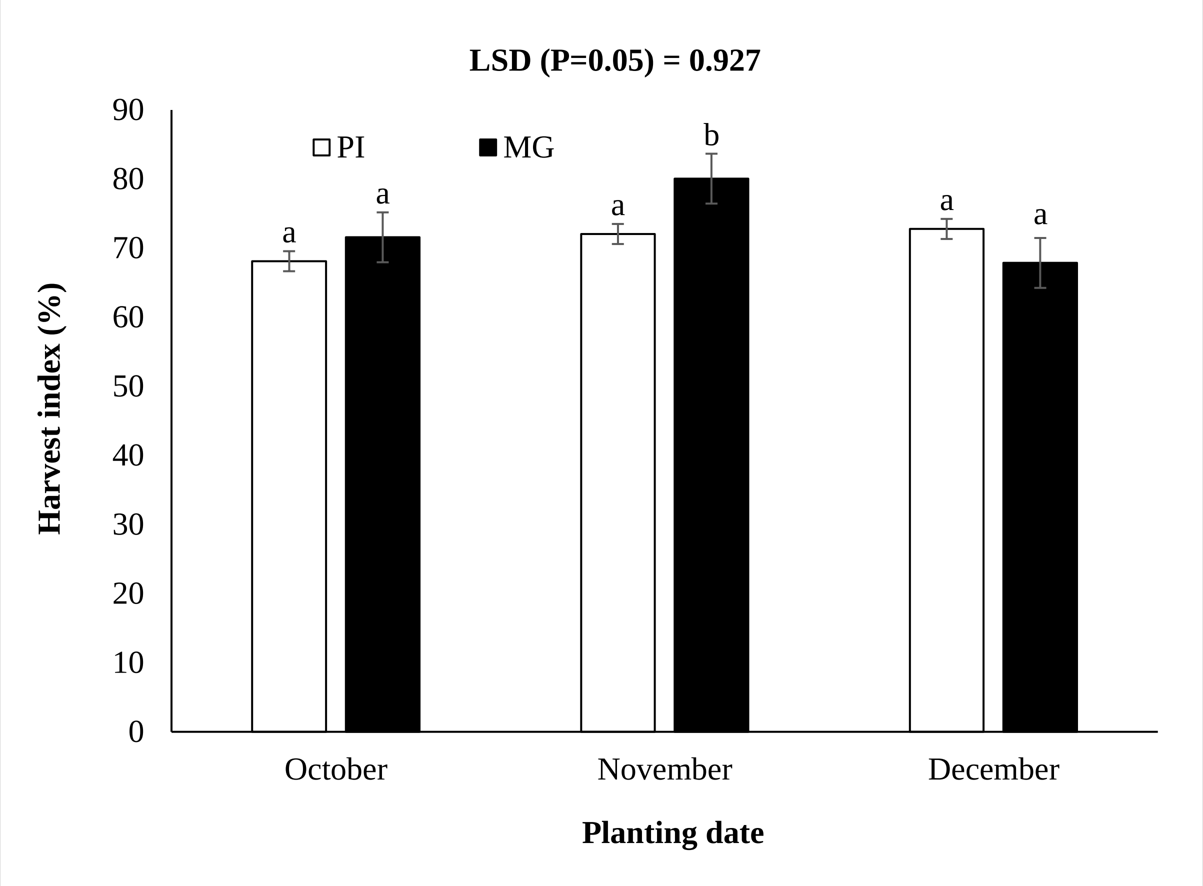

Figure 4.26: Effect of planting date and landraces (PI and MG) averaged across Gromor Accelerator® application rate on harvest index of taro cormels under dryland field conditions.

The application of organic fertiliser of 0 N kg per hectare displayed significantly higher HI for MG than PI when planting was done in October and November, but a further delay to December showed PI with higher HI than MG where October and December planting showed no difference between the landraces (Table 4.3). Delaying planting from October to November when 160 N kg per hectare of organic fertiliser was applied increased HI of MG than PI, whereas further delay in planting decreased HI of both landraces, where PI had high HI than

MG with no difference displayed between landraces when planting was done in October, November and December. However, when 320 N kg per hectare of organic fertiliser was applied HI significantly indicated an increase for MG than PI in November, while a further delay by two months in planting showed an increase in HI for PI only but a decrease for MG where landraces were not different in October and November. For both landraces, the highest HI was obtained when no organic fertiliser was applied with November planting, but MG yielded higher HI than PI obtaining.

Table 4.3: Effect of planting date and Gromor Accelerator® application rate on the harvest index (%) of taro cormels of different landraces under dryland field conditions. Means of the interaction effect within columns and rows followed by the same letter are not significant different from each other.

Planting date	**Landraces**	**Gromor Accelerator® (N kg ha^{-1})**		
		0	**160**	**320**
October	MG	75.22abcd	73.37abcd	66.11ab
	PI	64.68a	72.1abcd	67.55abc
November	MG	81.49d	78.59bcd	80.1cd
	PI	79.18cd	72.49abcd	64.47a
December	MG	67.59abc	70.16abcd	65.82a
	PI	73.89abcd	72.72abcd	71.72abcd
LSD **(P=0.05)**				6.802

4.3.10 Nutritional content

The mineral content of taro cormels was significantly (P< 0.05) affected by planting date and Gromor Gromor Accelerator® application rate and landraces with respect to elemental nutrients. The elemental nutrients that were significant (P<0.05) included, aluminium (Al), boron (B), calcium (Ca), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), phosphorus (P), total sulphur (S) and zinc (Zn) content of taro cormels from Ukulinga. The only elemental nutrients that were observed not significant ($P>0.05$) were carbon (C) and nitrogen (N) content of taro cormels.

4.3.10.1 Aluminium content

The aluminium content of taro corms was positively affected by the landraces ($P = 0.014$), planting date, Gromor Accelerator® application rate, the interaction of planting date and Gromor Accelerator® application rate ($P < 0.001$) at Ukulinga. The application rate of 160 and 320 N kg per hectare of organic fertiliser showed an increase in aluminium content of taro cormels when planting was done in October and there was no difference between the application rate of 0 and 160 N kg per hectare of organic fertiliser (Figure 4.27). Aluminium content was increased by delaying planting until November when 160 and 320 N kg per hectare of organic fertiliser was applied, followed by a significant decrease when planting was delayed by two months. The highest aluminium content was achieved by November planting when 160 N kg per hectare of organic fertiliser was applied, and the lowest aluminium content was observed with December planting when 160 N kg per hectare of organic fertiliser was applied.

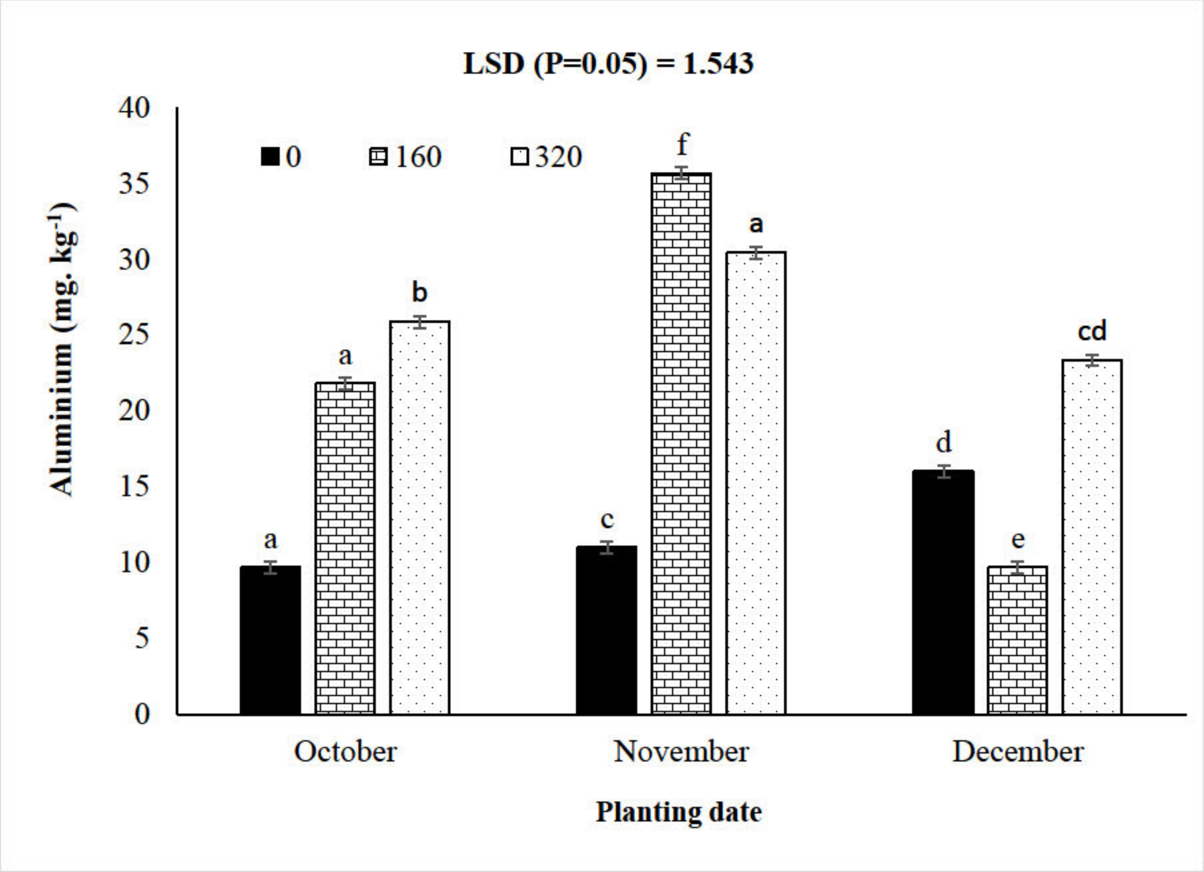

Figure 4.27: Effect of planting date and Gromor Accelerator® application rate (0, 160 and 320 N kg ha^{-1}) averaged across landraces on aluminium of taro cormels under dryland field conditions.

The interaction of Gromor Accelerator® application rate and landraces positively ($P < 0.001$) affected the aluminium content of taro corms at Ukulinga. The application of organic fertiliser significantly increased aluminium content for PI (Figure 4.28) when 160 and 320 N kg per hectare was applied. The application rate of 160 N kg per hectare of organic fertiliser significantly indicated MG with the highest aluminium content than PI, but a further increase of 320 N kg per hectare of organic fertiliser showed PI with the highest aluminium content than MG and all other organic fertiliser levels (Figure 4.28).

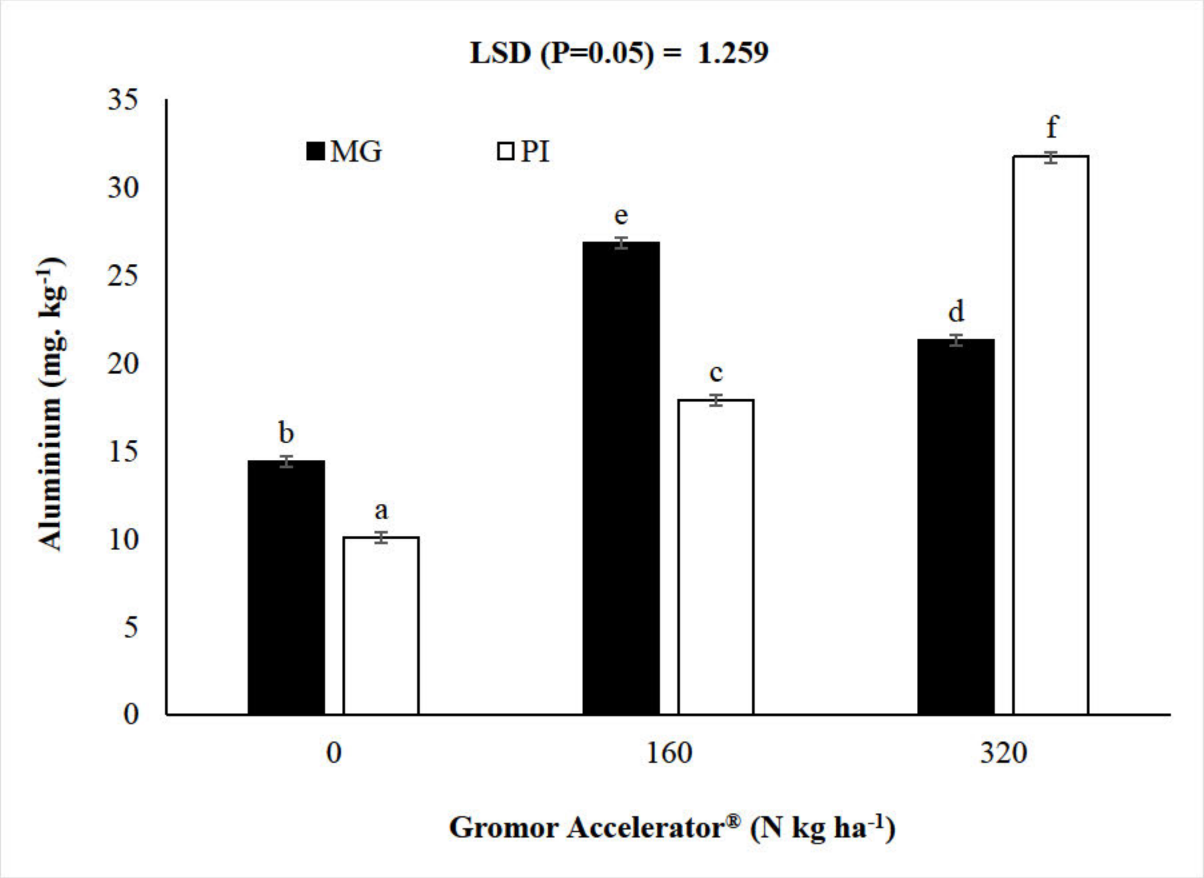

Figure 4.28: Effect of Gromor Accelerator® application rate and landraces (PI and MG) averaged across planting date on aluminium of taro cormels under dryland field conditions.

The results showed that the interaction of landraces and delayed planting dates ($P < 0.001$) significantly affected aluminium content of taro corms at Ukulinga. Demonstrated by Figure 4.29 below, delaying planting from October to November planting significantly increased aluminium content of MG and PI where PI was not different in October and November planting. Aluminium content was observed with a decrease for MG and PI when planting was further delayed by two months. When planting was done in October PI had higher aluminium content than MG, whereas MG had the highest aluminium content for November and December planting, respectively (Figure 4.29).

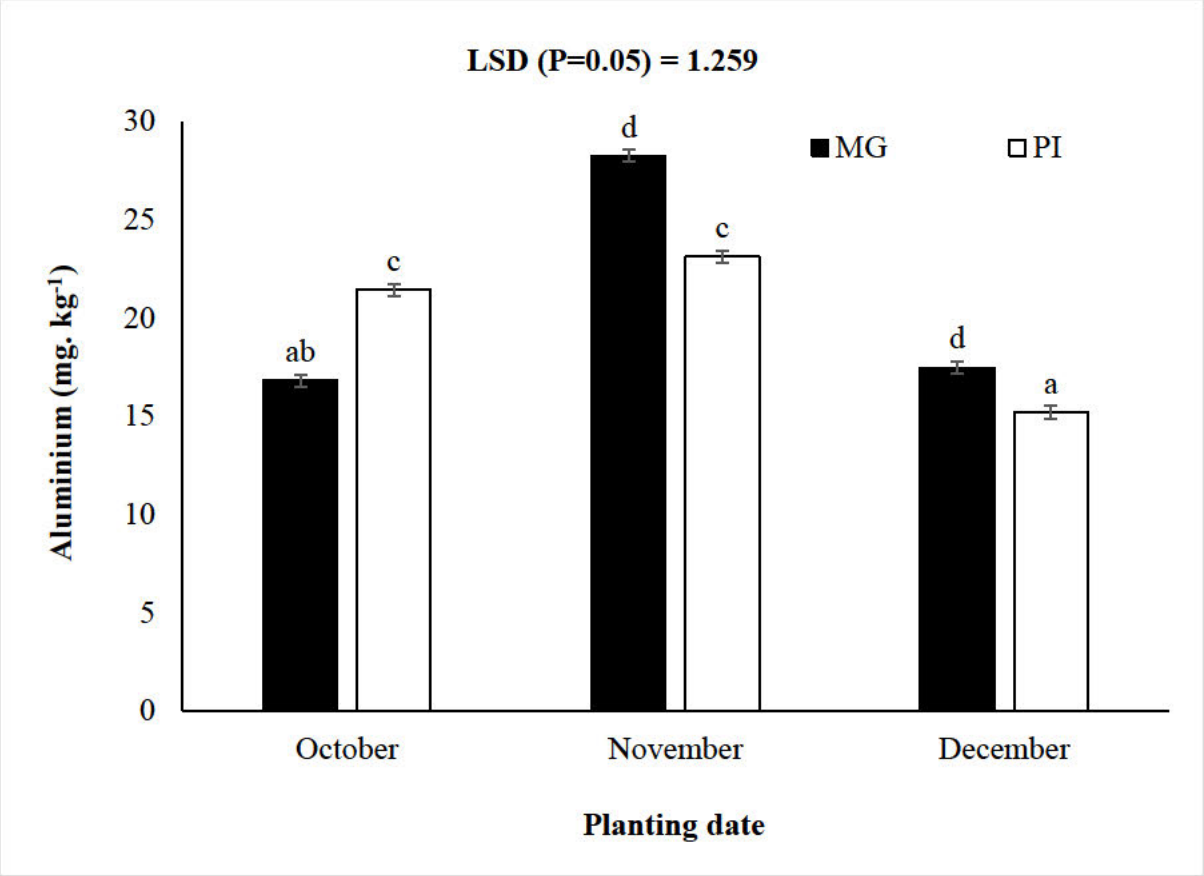

Figure 4.29: Effect of planting date and landraces (PI and MG) averaged across Gromor Accelerator® application rate on aluminium of taro cormels under dryland field conditions.

The interaction of planting date, landraces and Gromor Accelerator® application rate was observed to be significantly different on aluminium content ($P<0.001$) of taro corms. When 0 N kg per hectare of organic fertiliser was applied, delaying planting of MG and PI from October to December increased aluminium content of taro corms, whereas MG and PI were not significantly different when planting was delayed by two months (Table 4.4). Delaying planting from October to November when 160 N kg per hectare of organic fertiliser was applied increased aluminium content of MG but decreased for PI, where a further delay in planting by two months decreased the aluminium content for both landraces. There was also no difference between landraces when planting was done in October. However, when 320 N kg per hectare of organic fertiliser was applied delaying planting from October to December showed an increase in aluminium content for MG while for PI an increase in aluminium content was observed with one month delay in planting then a decrease in December planting. For November planting MG (50.53 mg kg^{-1}) obtained the highest aluminium content with 160 N kg per hectare of organic fertiliser, while PI (39.91 mg kg^{-1}) obtained the highest with 320 N kg per hectare of organic fertiliser during November planting.

Table 4.4: Effect of planting date and Gromor Accelerator® application rate on aluminium (mg kg^{-1}) of taro cormels of different landraces under dryland field conditions. Means of the interaction effect within columns and rows followed by the same letter are not significantly different from each other.

Planting date	**Landraces**	**Gromor Accelerator® (N kg ha^{-1})**		
		0	**160**	**320**
October	MG	13.22cd	21.82g	15.39cde
	PI	6.16a	21.82g	36.29i
November	MG	13.32cd	50.53j	20.89fg
	PI	8.69ab	20.76fg	39.91i
December	MG	16.62def	8.17ab	27.63h
	PI	15.4cde	11.18bc	19.02efg
LSD **(P=0.05)**				2.181

4.3.10.2 Boron content

Boron content of taro cormels was significantly affected by planting date, Gromor Accelerator® application rate ($P < 0.001$), and the interaction of Gromor Accelerator® application rate and landraces ($P = 0.049$) at Ukulinga. However, there was no significant effect of landrace and the interaction of the Gromor Accelerator® application rate and planting date and also the interaction planting date and landraces on boron content ($P>0.05$). When no organic fertiliser was applied, no difference was indicated between landraces, where the addition of 160 N kg per hectare of organic fertiliser showed MG with a higher boron content than PI (Figure 4.30). But further application of 320 N kg per hectare of organic fertiliser showed PI with the highest boron content than all other organic fertiliser levels. MG and PI had significantly lower boron content when the landraces were planted without fertiliser than with organic fertiliser.

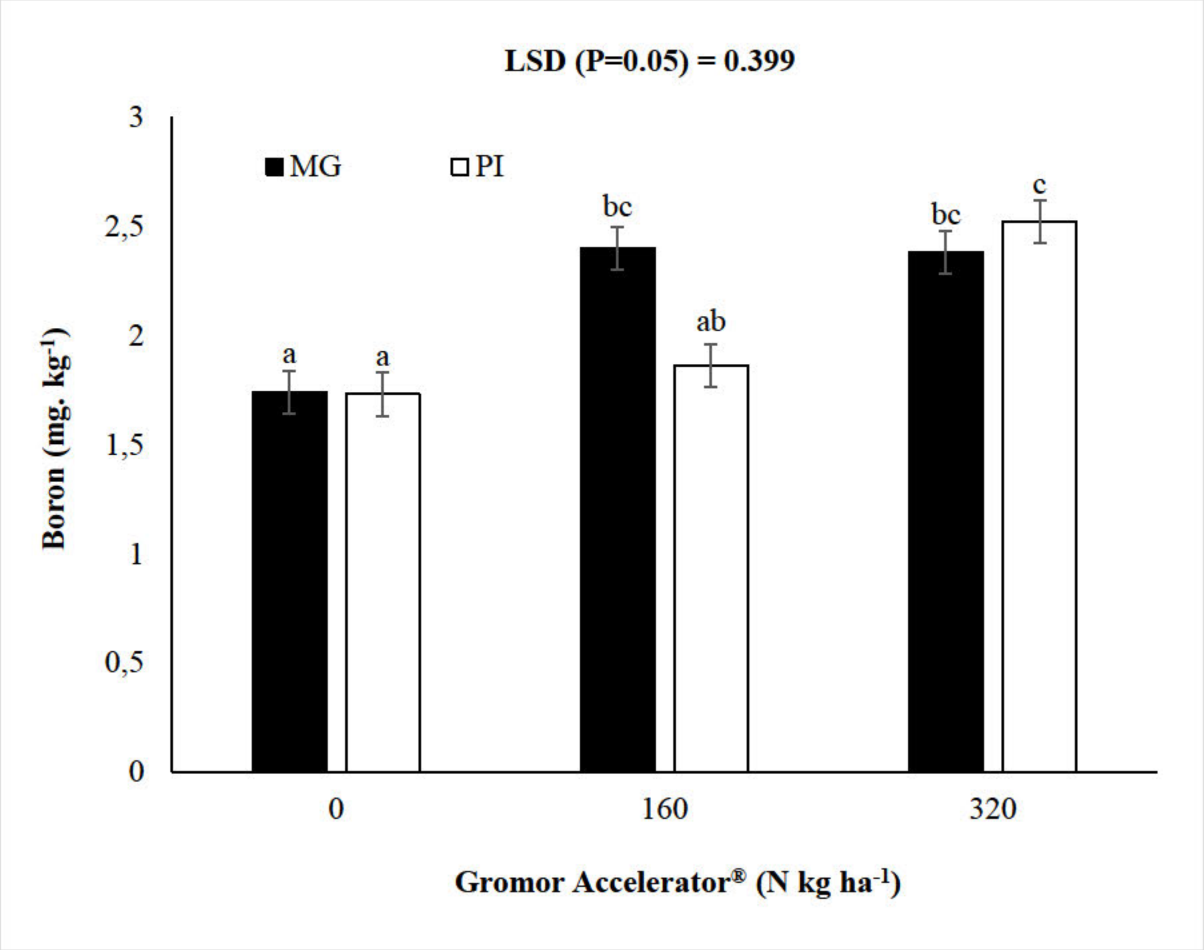

Figure 4.30: Effect of Gromor Accelerator® application rate and landraces (PI and MG) averaged across planting date on boron of taro cormels under dryland field conditions.

The boron content of taro cormels was positively affected by the interaction effect of planting date, landraces and Gromor Accelerator® application rate ($P = 0.021$). When no organic fertiliser was applied delaying planting until December significantly increased boron content for both landraces compared to October and November planting respectively where the application of organic fertiliser indicated no difference in boron content of MG and PI between October, November and December planting (Table 4.5). For 160 N kg per hectare of organic fertiliser with delayed planting from October to November showed a decrease in boron content for PI but an increase for MG whereas a further delay in planting by two months increased boron content for PI while for MG it was decreased and October, November and December showed no difference among landraces. When 320 N kg per hectare of organic fertiliser was applied, delaying planting from November to December increased boron content for both landraces with no significant difference between MG and PI when planting was done in October, November and December. MG (3.20 mg kg^{-1}) and PI (2.74 mg kg^{-1}) obtained their highest boron content with 320 N kg ha^{-1} of organic fertiliser when planting was delayed by two months than with 160 and 0 N kg per hectare of organic fertiliser.

Table 4.5: Effect of planting date and Gromor Accelerator® application rate on boron (mg. kg^{-1}) of taro cormels of different landraces under dryland field conditions. Means of the interaction effect within columns and rows followed by the same letter are not significantly different from each other.

Planting date	**Landraces**	**Gromor Accelerator® (N kg ha^{-1})**		
		0	**160**	**320**
October	MG	1.56a	2.43ab	1.76a
	PI	1.57a	1.79a	2.44ab
November	MG	1.54a	2.64ab	2.16ab
	PI	1.49a	1.42a	2.36ab
December	MG	2.12ab	2.13ab	3.2ab
	PI	2.14ab	2.38ab	2.74b
LSD (P=0.05)				0.691

4.3.10.3 Calcium content

The effect of the Gromor Accelerator® application rate (P = 0.003), planting date, and interaction effect of planting date and Gromor Accelerator® application rate was highly significant (P<0.001) on the calcium content of taro corms at Ukulinga. The landraces were observed to have no significant effect on calcium content (P>0.05). When the planting was done in October addition of organic fertiliser significantly did not enhance the calcium content where there was no difference between the application of 0 and 160 N kg per hectare of organic fertiliser (Figure 4.31). Calcium content was increased by delaying planting until November when 320 N kg per hectare of organic fertiliser was applied, where the application of 320 N kg per hectare displayed November and December planting with the same highest calcium content. The highest (0.07%) calcium content was achieved with November and December planting when 320 N kg per hectare of organic fertiliser was applied, while the lowest was obtained when 160 and 320 N kg per hectare of organic fertiliser was applied in October.

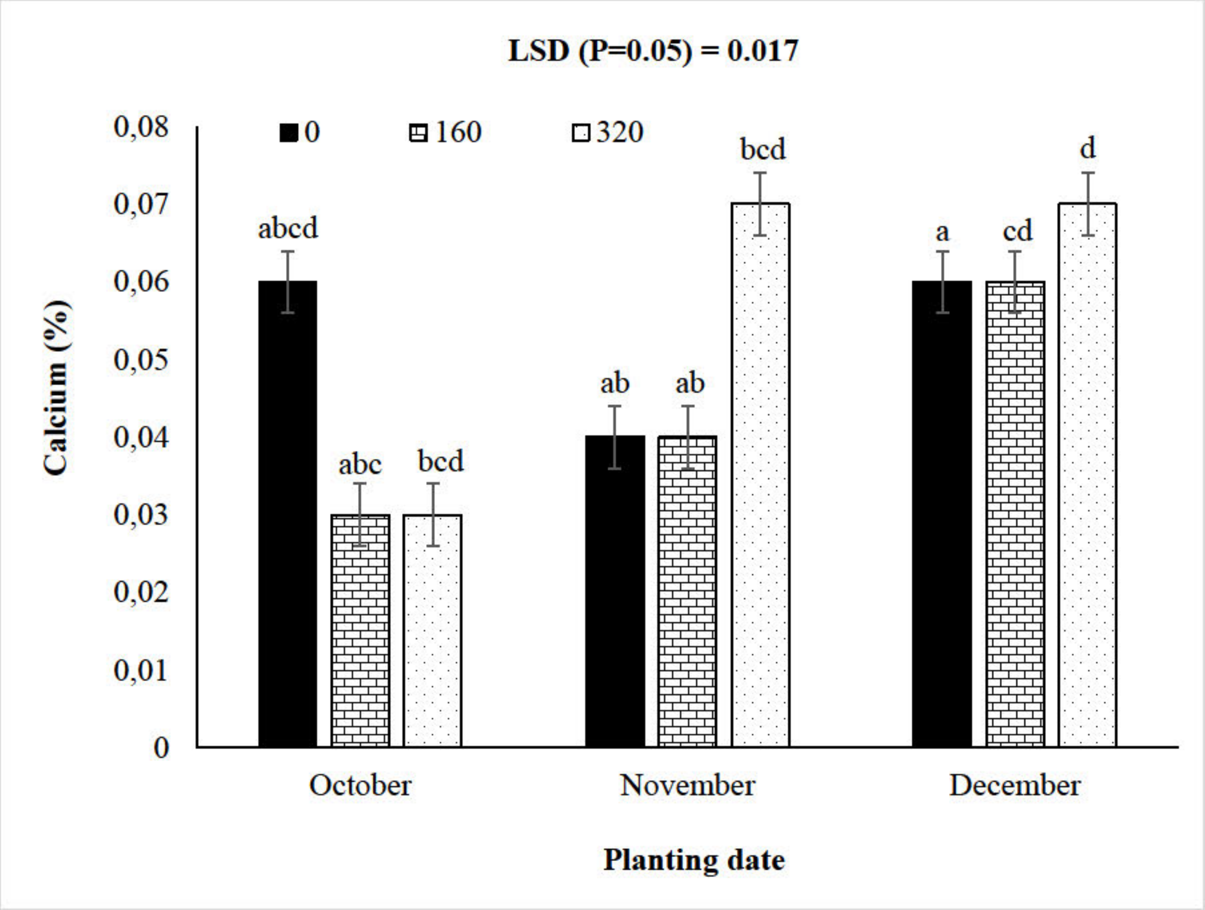

Figure 4.31: Effect of planting date and Gromor Accelerator® application rate (0, 160 and 320 N kg ha^{-1}) averaged across landraces on the calcium of taro cormels under dryland field conditions.

There was a significant (P = 0.019) effect between the interaction of the Gromor Accelerator® application rate and landrace on the calcium content of taro corms at Ukulinga. Application of 0 and 160 N kg per hectare organic fertiliser only increased the calcium content more for PI compared to MG, whereas a further increase in organic fertiliser of 302 N kg per hectare enhanced the calcium content for MG only with landraces not showing any difference when 0, 160 and 320 N kg per hectare organic fertiliser (Figure 4.32). PI had the highest (0.06%) calcium content with 0 N kg per hectare of organic fertiliser than when 160 and 320 N kg per hectare of organic fertiliser was applied, whereas MG (0.06%) had the highest calcium content with 320 N kg per hectare of organic fertiliser than with 160 N kg per hectare of organic fertiliser was applied.

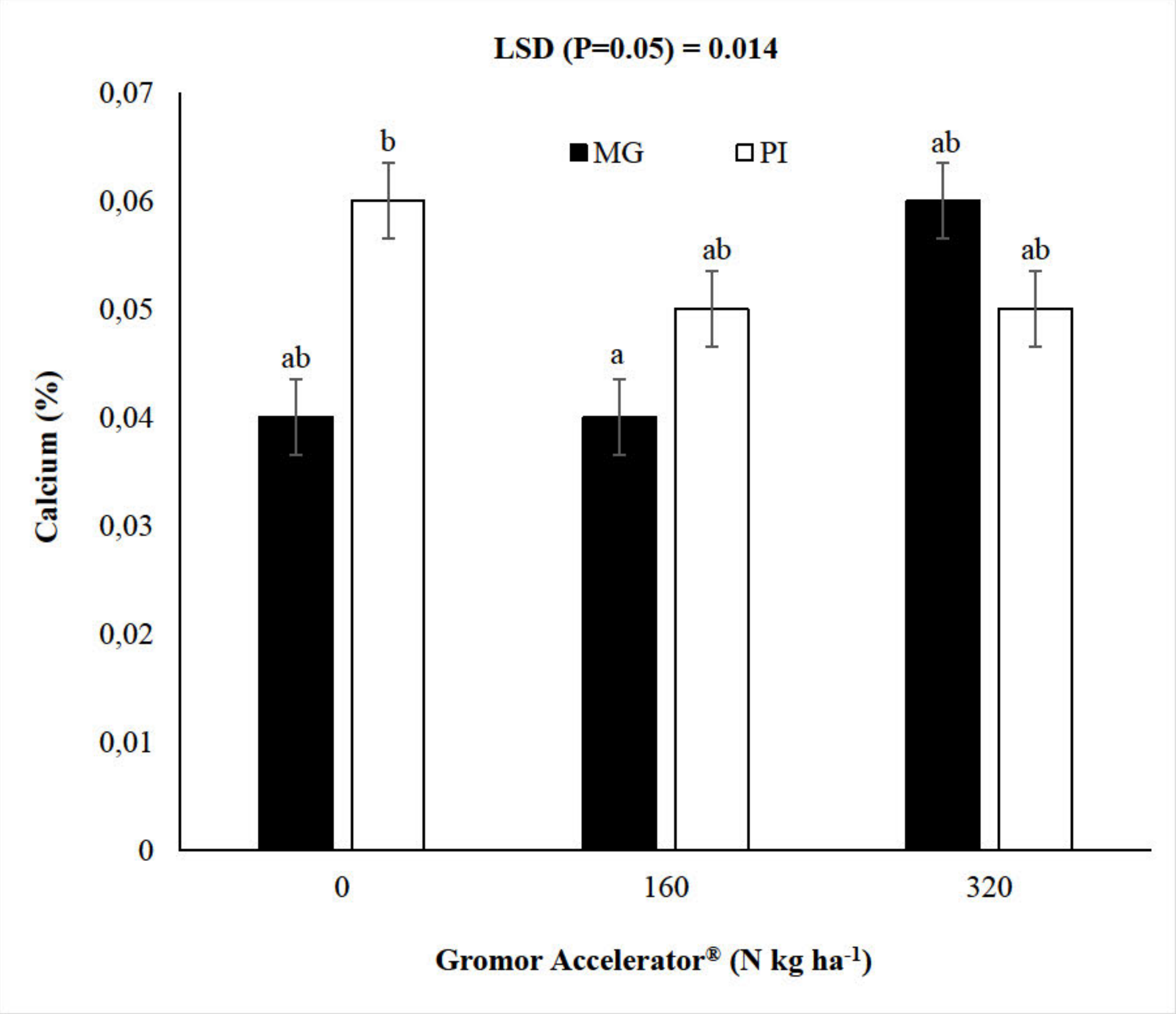

Figure 4.32: Effect of Gromor Accelerator® application rate and landraces (PI and MG) averaged across planting date on the calcium of taro cormels under dryland field conditions.

The interaction of planting date and landrace significantly affected the calcium content of taro cormels at Ukulinga (P = 0.038). Early planting date October only enhanced calcium content for PI than MG, and delaying planting by one and two months significantly increased calcium content at the same rate for MG and PI (Figure 4.33). Delaying planting from October to November and December planting indicated MG and PI with the corresponding increase in calcium content. MG and PI had higher (0.06%) calcium content than other planting dates when they were planted in December, where no difference was shown between the landraces. There was no significant effect of the difference between MG and PI when planting was done in October and November.

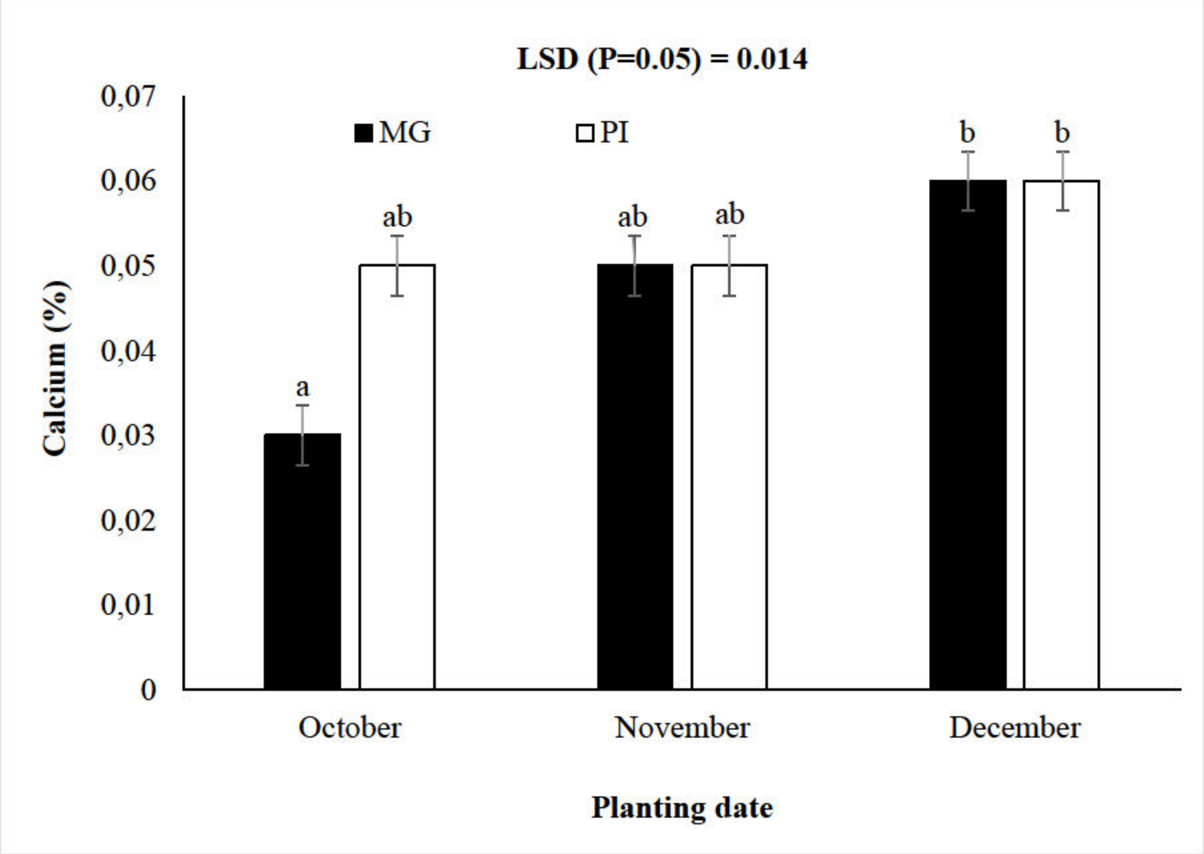

Figure 4.33: Effect of planting date and landraces (PI and MG) averaged across Gromor Accelerator® application rate on the calcium of taro cormels under dryland field conditions.

There was a significant (P = 0.017) interaction between planting date, landrace and Gromor Accelerator® application rate with respect to the calcium content of taro corms at Ukulinga. When no organic fertiliser was applied, delaying planting of MG and PI from October to November decreased calcium content of MG and PI but a further delay of planting to December increased calcium content for MG, followed by a decrease for PI where landraces were not different when planted in November and December (Table 4.6). Delaying planting of PI from October to December when 320 N kg per hectare of organic fertiliser was applied significantly increased calcium content, whereas for MG delaying planting from October to November significantly increased calcium content followed by a decrease when planting was further delayed by two months where MG and PI were not different. MG obtained the highest calcium content significantly with 320 than with 160 N kg per hectare of organic fertiliser when planting was done in November. PI significantly achieved the highest calcium content with 0 and 320 N kg per hectare of organic fertiliser when planting was done in October and December, respectively.

Table 4.6: Effect of planting date and Gromor Accelerator® application rate on calcium (%) of taro cormels of different landraces under dryland field conditions. Means of the interaction effect within columns and rows followed by the same letter are not significantly different from each other.

Planting date	**Landraces**	**Gromor Accelerator® (N kg ha^{-1})**		
		0	**160**	**320**
October	MG	0.04abc	0.02a	0.02a
	PI	0.07bc	0.04abc	0.03ab
November	MG	0.02a	0.04ab	0.09c
	PI	0.06abc	0.04ab	0.05abc
December	MG	0.06abc	0.06abc	0.07bc
	PI	0.05abc	0.06abc	0.07bc
LSD (P=0.05)				0.023

4.3.10.4 Copper content

The copper content of taro corms was positively affected by delayed planting and Gromor Accelerator® application rate ($P < 0.001$) at Ukulinga. Landraces, the interactions of landrace and planting date, and the Gromor Accelerator® application rate and planting date as well as of planting date, landrace and Gromor Accelerator® application rate were all observed not to play any significant role ($P>0.05$) with respect to copper content. Delaying planting by one month showed a decrease in copper content, while a further delay to December planting significantly increased the level of copper content (Figure 4.34). December planting displayed significantly the highest copper content (7.55 mg kg^{-1}) followed by October planting (5.87 mg kg^{-1}) and November planting with the lowest copper content (5.37 mg kg^{-1}) where October and November planting observed not to be significantly different from each other.

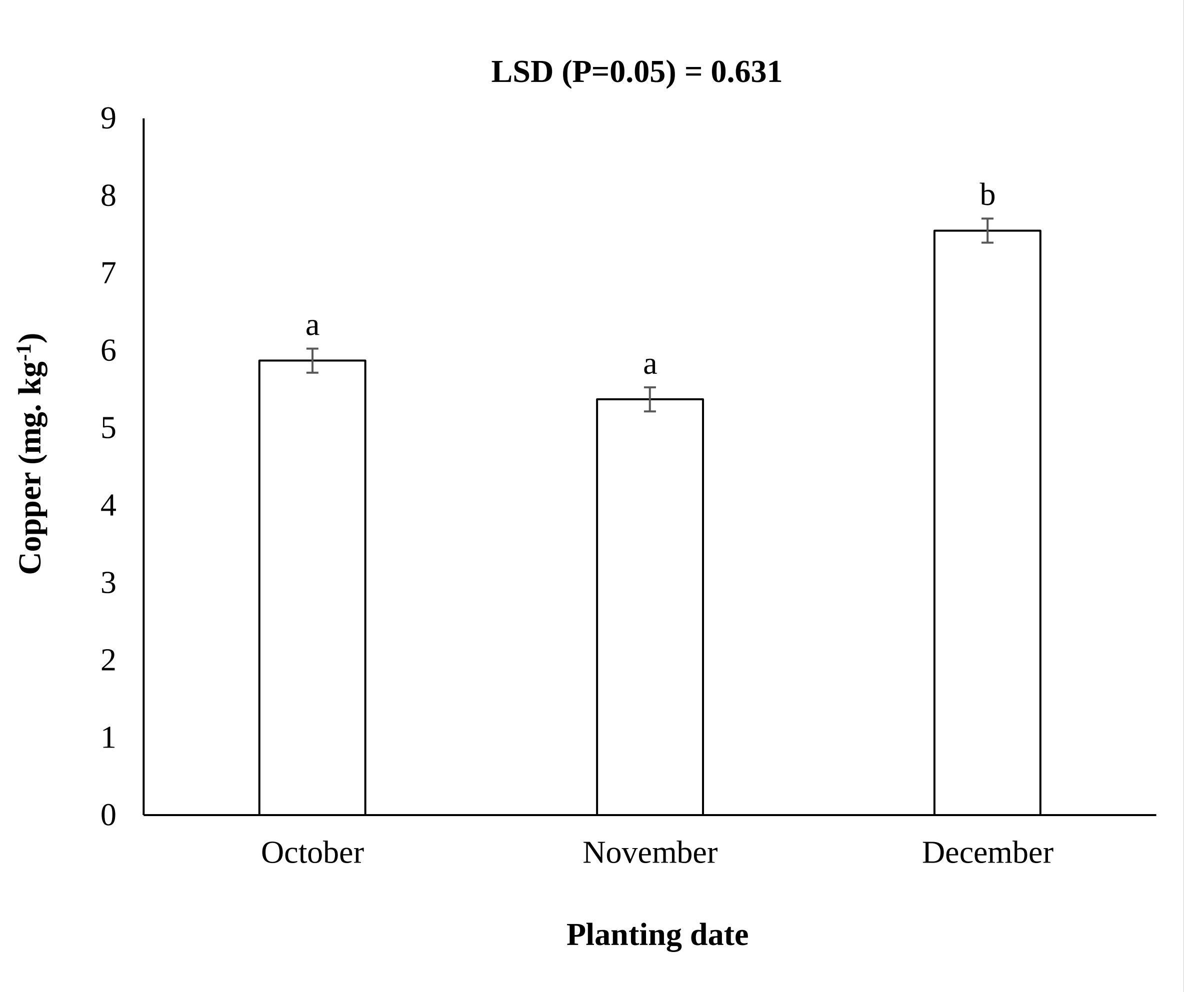

Figure 4.34: Effect of planting date averaged across landraces and Gromor Accelerator® application rate on copper of taro cormels under dryland field conditions.

There was a highly significant difference ($P<0.001$) between the interaction Gromor Accelerator® application rate and landrace on the copper content of the taro corms at Ukulinga. The application rate of 0 N kg per hectare of organic fertiliser yielded the lowest copper content for MG and PI, whereas the addition of 160 N kg per hectare of organic fertiliser showed a significant increase in copper content MG than PI (Figure 4.35). When 320 N kg per hectare of organic fertiliser was applied, PI significantly yielded the highest copper content than MG. There was no difference in copper content between the landraces when 0 N kg per hectare of organic fertiliser was applied.

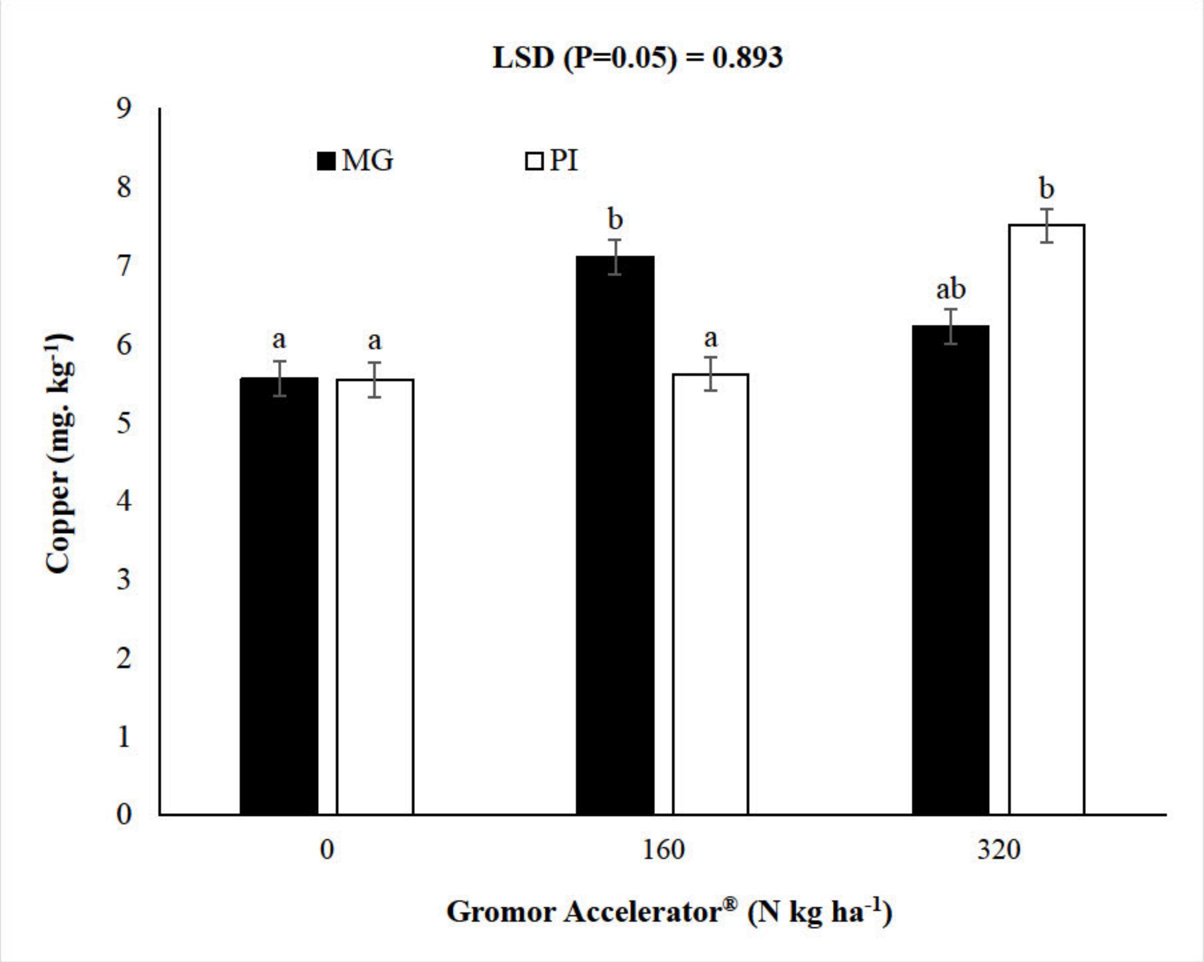

Figure 4.35: Effect of Gromor Accelerator® application rate and landraces (PI and MG) averaged across planting date on copper of taro cormels under dryland field conditions.

4.3.10.5 Iron content

The iron content of taro corms was positively affected by Gromor Accelerator® application rate ($P = 0.021$) at Ukulinga. Planting date, landrace and their interactions, including planting date, landrace, and Gromor Accelerator® application rate, were all not significant with respect to the iron content ($P>0.05$). The iron content of taro corms was only enhanced by the application of 320 N kg per hectare of organic fertiliser which significantly obtained the highest iron content compared to other organic fertiliser application rates (Figure 4.36). However, the application of 0 N kg per hectare of organic fertiliser showed a higher iron content of taro corms than the application of 160 N kg per hectare of organic fertiliser whereas, there was no difference in iron content of taro corms when 0 and 160 N kg per hectare was applied.

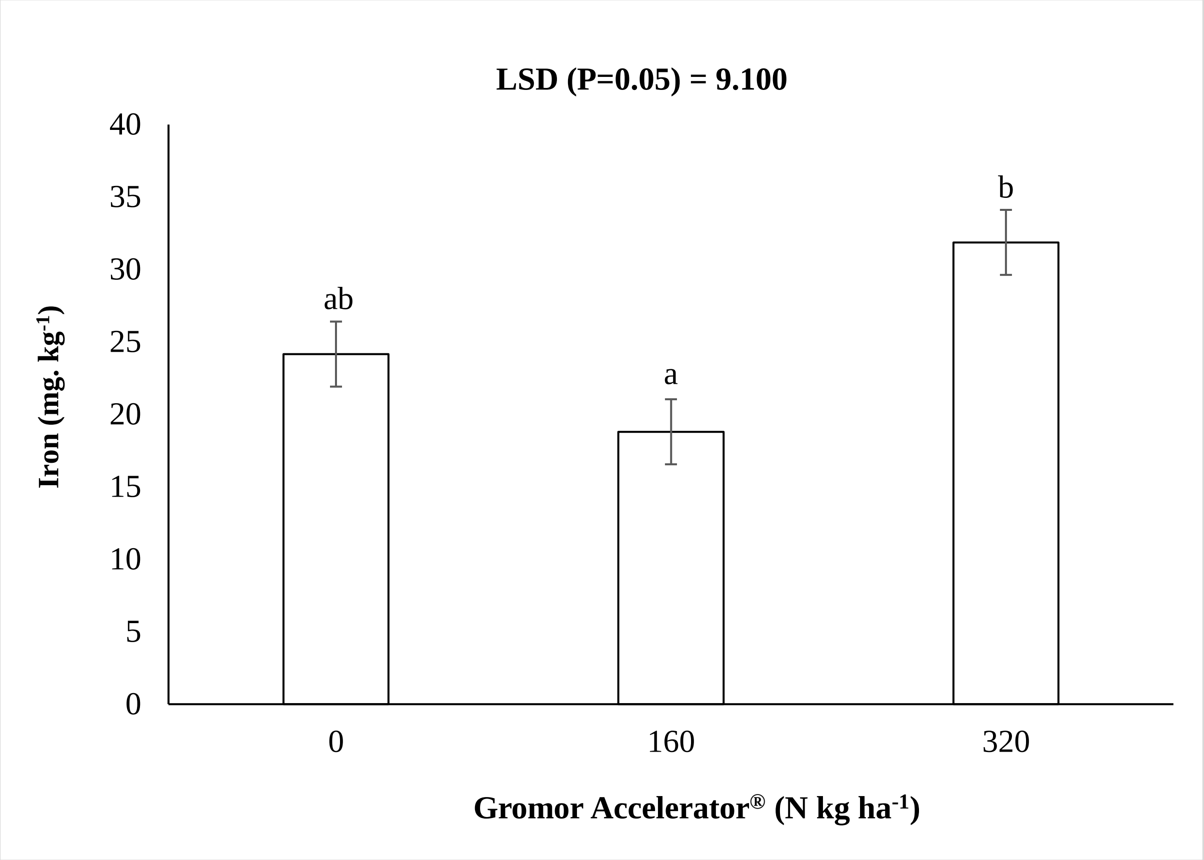

Figure 4.36: Effect of Gromor Accelerator® application rate averaged across planting date and landraces on the iron of taro cormels under dryland field conditions.

4.3.10.6 Potassium content

Potassium content was significantly affected by landraces ($P = 0.003$), planting date, Gromor Accelerator® application rate, and the interaction of Gromor Accelerator® application rate and planting date ($P<0.001$) at Ukulinga. There was no significant effect of landrace on the potassium content of taro corms ($P>0.05$). October planting displayed a significant increase in potassium content of taro corms when the application rate was increased from 0 to 160 and 320 N kg per hectare of organic fertiliser where the application of no fertiliser was not different from 160 N kg per hectare of organic fertiliser (Figure 4.37). Delaying planting by one month when 160 and 320 N kg per hectare of organic fertiliser was applied displayed an increase in potassium content significantly higher than in October planting. Two months delay in planting was observed with the highest potassium content of taro corms with the addition of 320 than with 160 N kg per hectare of organic fertiliser while, the lowest potassium content was obtained with October planting with 0 N kg per hectare of organic fertiliser. There was also no difference in potassium content between October and November when 160 and 320 N kg per hectare of organic fertiliser was applied.

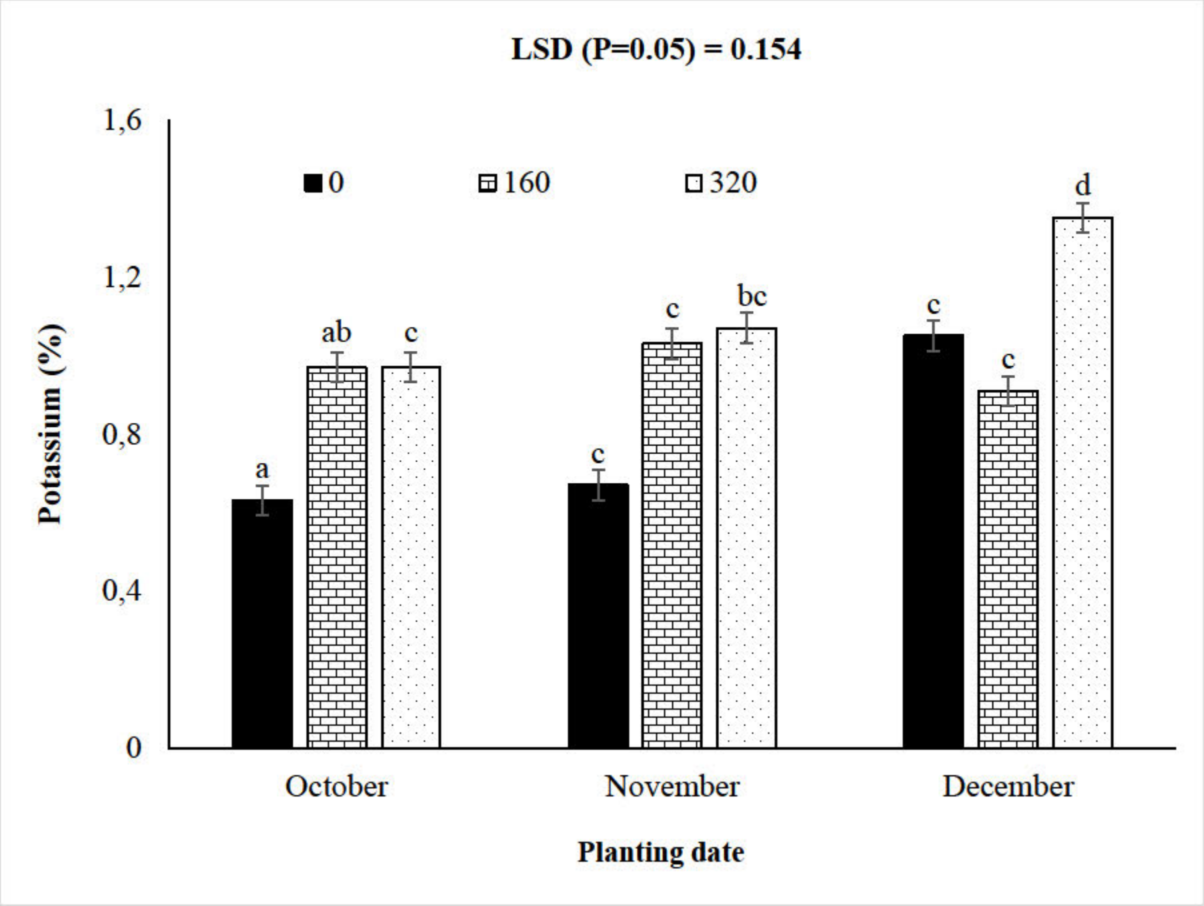

Figure 4.37: Effect of planting date and Gromor Accelerator® application rate (0. 160 and 320 N kg ha^{-1}) averaged across landraces on the potassium of taro cormels under dryland field conditions.

At Ukulinga, the interaction of Gromor Accelerator® application rate and landraces ($P < 0.001$) displayed a significant effect on the potassium content of taro cormels. The application of organic fertiliser increased potassium content for both landraces when 160 and 320 N kg per hectare of organic fertiliser was applied (Figure 4.38). PI was observed with the highest (1.16%) potassium content than MG (1.1%) when 320 N kg per hectare of organic fertiliser was applied. When 0 N kg per hectare of organic fertiliser was applied, MG (0.82%) significantly yielded higher potassium content than PI (0.76%), whereas a further increase of 160 N kg per hectare of organic fertiliser showed MG (1.13%) with highest potassium content than PI (0.80%). There was no difference between landraces when 0 and 160 N kg per hectare of the organic fertiliser was applied.

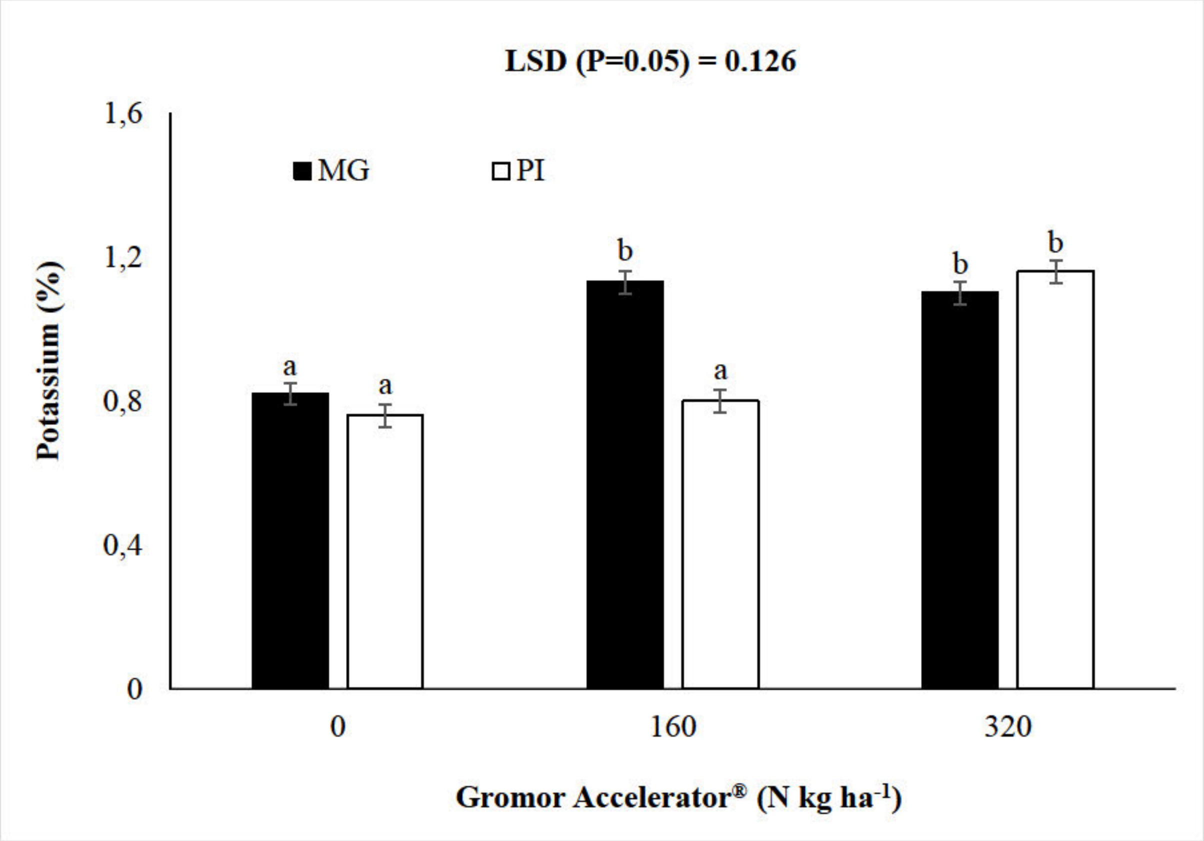

Figure 4.38: Effect of Gromor Accelerator® application rate and landraces (PI and MG) averaged across planting date on the potassium of taro cormels under dryland field conditions.

There was significant ($P<0.001$) interaction between planting date, landrace and Gromor Accelerator® application rate in the potassium content of taro corms at Ukulinga. Application of 0 N kg per hectare organic fertiliser when planting was delayed by one and two months showed an increase in the potassium content of corms for PI, whereas MG had a decrease in the potassium content when planting was done in November, then followed by an increase when the planting was delayed until December (Table 4.7). When 160 N kg per hectare of organic fertiliser was applied, potassium content for PI was significantly increased with delayed planting from October to December, whereas for MG, its potassium content of corms was increased with November planting only then decreased with December planting. Addition of organic fertiliser 320 N kg per hectare showed MG with an increase in the potassium content of corms when planting was delayed by one and two months, while for PI delaying planting by one and two months did not significantly improve the potassium content. For MG (1.54%) and

PI (1.54%), the highest potassium content of corms was obtained with the application of 320 N kg per hectare of organic fertiliser when planting was done in December.

Table 4.7: Effect of planting date and Gromor Accelerator® application rate on potassium (%) of taro cormels of different landraces under dryland field conditions. Means of the interaction effect within columns and rows followed by the same letter are not significantly different from each other.

Planting date	**Landraces**	**Gromor Accelerator® (N kg ha^{-1})**		
		0	**160**	**320**
October	MG	0.75abcd	1.26fg	0.76abcde
	PI	0.52a	0.68ab	1.18efg
November	MG	0.74abcd	1.33fg	1.00bcdef
	PI	0.61ab	0.72abc	1.14cdefg
December	MG	0.96bcdef	0.81abcde	1.54g
	PI	1.14cdefg	1.01bcdef	1.15defg
LSD (P=0.05)				0.218

4.3.10.7 Magnesium content

The planting date (P<0.001), landraces (P = 0.040), Gromor Accelerator® application rate (P = 0.006), the interactions of Gromor Accelerator® application rate and planting date (P<0.001), Gromor Accelerator® application rate and landrace (P = 0.033), as well as of planting date, landraces and Gromor Accelerator® application rate (P = 0.008) all were observed to have a significant effect on magnesium content at Ukulinga. However, only the interaction of planting date and landrace was not significant (P>0.05). The addition of organic fertiliser significantly did not enhance magnesium content of taro corms when planting was done in October and November, where 0 N kg per hectare of organic fertiliser was significantly higher than 160 and

320 N kg per hectare of organic fertiliser levels in October (Figure 4.39). Delaying planting until November significantly increased magnesium content when organic fertiliser was applied, but the application rate of 160 and 320 N kg per hectare of organic fertiliser was not significantly different. Delaying planting by two months significantly increased the magnesium content when 0 and 320 N kg per hectare of organic fertiliser was applied, whereas the application rates of 0 and 160 N kg per hectare of organic fertiliser were not significantly different from each other. When the planting was done in December, applying 0 and 320 N kg per hectare of organic fertiliser yielded the highest magnesium content than other organic fertiliser application rates.

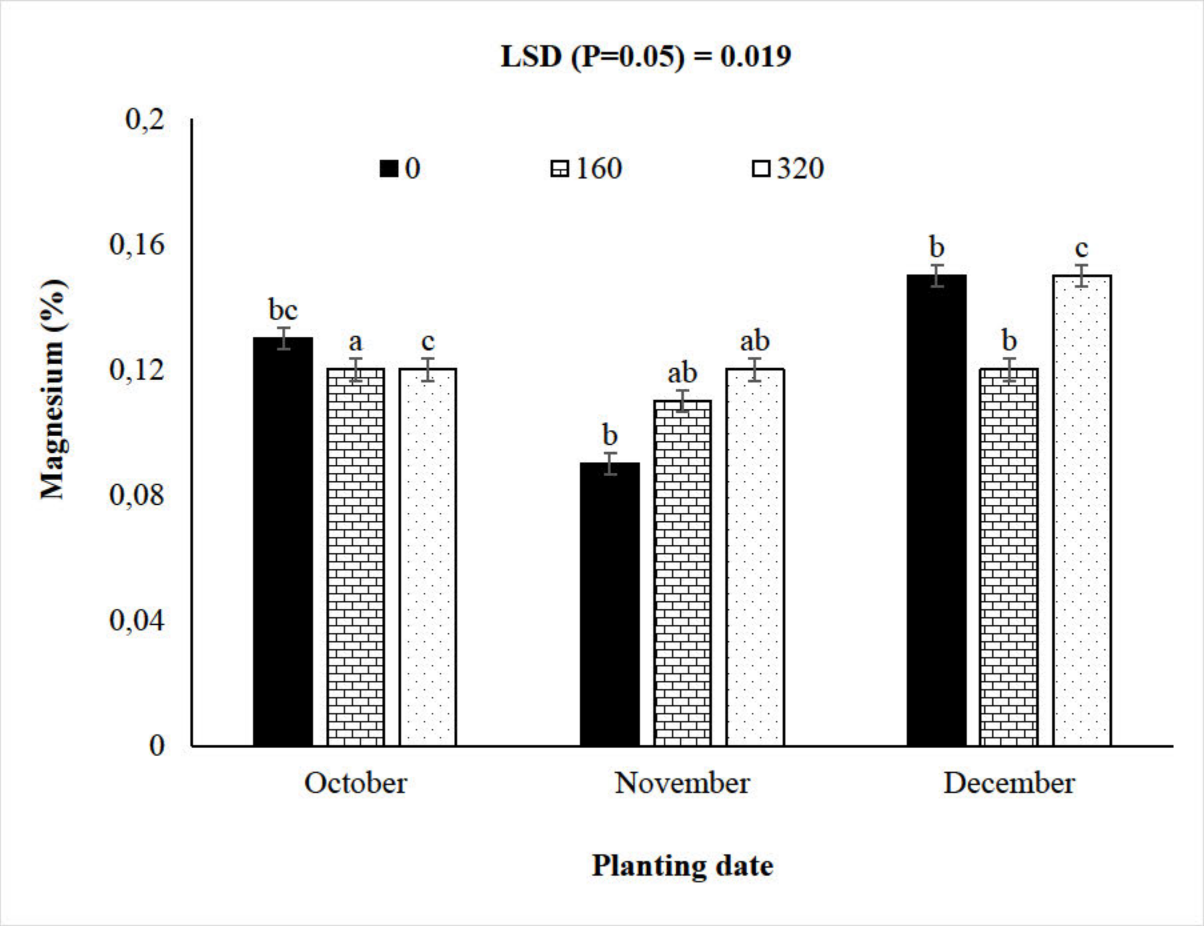

Figure 4.39: Effect of planting date and Gromor Accelerator® application rate (0. 160 and 320 N kg ha^{-1}) averaged across landraces on the magnesium of taro cormels under dryland field conditions.

When 0 N kg per hectare of Gromor Accelerator® was applied, PI obtained the highest (0.13 mg kg^{-1}) magnesium content than MG (0.12 mg kg^{-1}) (Figure 4.40). The addition of 160 N kg per hectare of organic fertiliser significantly did not improve magnesium content, whereas a further increase in organic fertiliser of 320 N kg per hectare showed an increase in magnesium content for both landraces. There were no significant differences in magnesium content between MG and PI when 0, 160, and 320 N kg per hectare of organic fertiliser was applied.

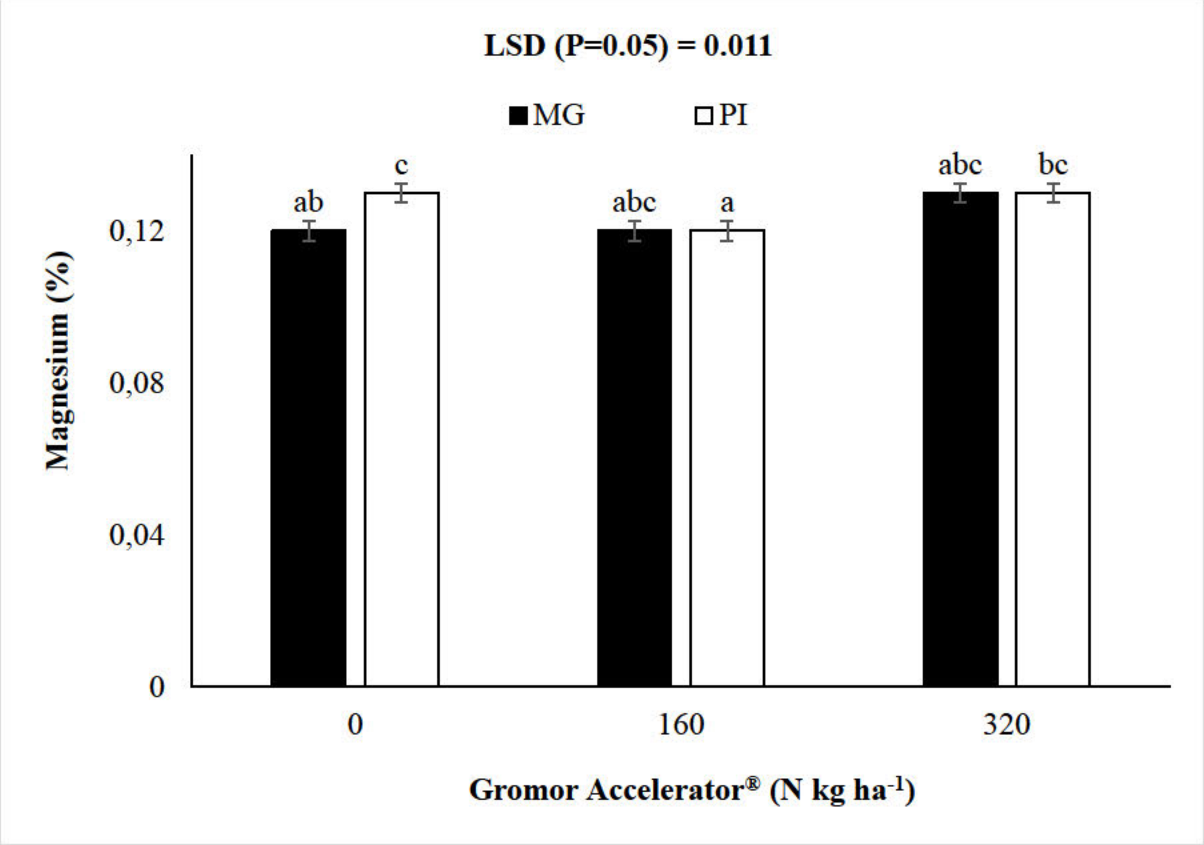

Figure 4.40: Effect of Gromor Accelerator® application rate and landraces (MG and PI) averaged across planting date on the magnesium of taro cormels under dryland field conditions.

Delaying planting until November decreased magnesium content for MG, and PI thereafter significantly increased with December planting but PI yielding higher magnesium content when no organic fertiliser was applied; however, there was significant effect between October and November planting date (Table 4.8). Application of 160 N kg per hectare of organic fertiliser significantly did not enhance the magnesium content of MG and PI when planting was delayed until November and December, whereas MG and PI were not significantly different in October and November. An additional of 320 N kg per hectare of organic fertiliser increased magnesium content of MG but decreased for PI during November planting, followed by an increase in magnesium content for both landraces similar increase as of 0 N kg per hectare of organic fertiliser when planting was delayed until December. MG and PI yielded the highest magnesium, respectively, with 0 and 320 N kg per hectare of organic fertiliser respectively, when planting was delayed until December, where PI had higher magnesium content compared to MG.

Table 4.8: Effect of planting date and Gromor Accelerator® application rate on magnesium (%) of taro cormels of different landraces under dryland field conditions. Means of the interaction effect within columns and rows followed by the same letter are not significantly different from each other.

Planting date	**Landraces**	**Gromor Accelerator® (N kg ha^{-1})**		
		0	**160**	**320**
October	MG	0.13bc	0.12bc	0.11ab
	PI	0.13bc	0.12bc	0.13bc
November	MG	0.08a	0.11ab	0.13bc
	PI	0.11ab	0.11ab	0.11
December	MG	0.14bc	0.12bc	0.14bc
	PI	0.16c	0.11ab	0.16c
LSD (P=0.05)				0.019

4.3.10.8 Manganese content

Manganese content of taro cormels was significantly affected by the planting date, landraces, Gromor Accelerator® application rate (P<0.001) at Ukulinga. There was also a significant effect in the interaction of planting date and Gromor Accelerator® application rate with respect to manganese content (P<0.001). Delaying planting until December significantly increased manganese content of taro cormels when no fertiliser was applied, followed by a significant decrease with the application of 160 and 320 N kg per hectare of organic fertiliser when planting was done in October, November, and December (Figure 4.41). The addition of 320 N kg per hectare of organic fertiliser significantly did not improve the manganese content of taro corms when planting was delayed until November and December. Applying 160 and 320 N kg per hectare of organic fertiliser when planting was done in November significantly decreased manganese content, whereas no significant effect was observed between 0 and 160 N kg per hectare of organic fertiliser during October planting. There was no significant difference in manganese content showed between November and December planting when 0 and 320 N kg per hectare of organic fertiliser was applied. When the planting was done in December, applying 0 N kg per hectare of organic fertiliser yielded the highest magnesium content than other fertiliser application rates in all planting dates and the 320 N kg per hectare of organic fertiliser obtaining the lowest in November.

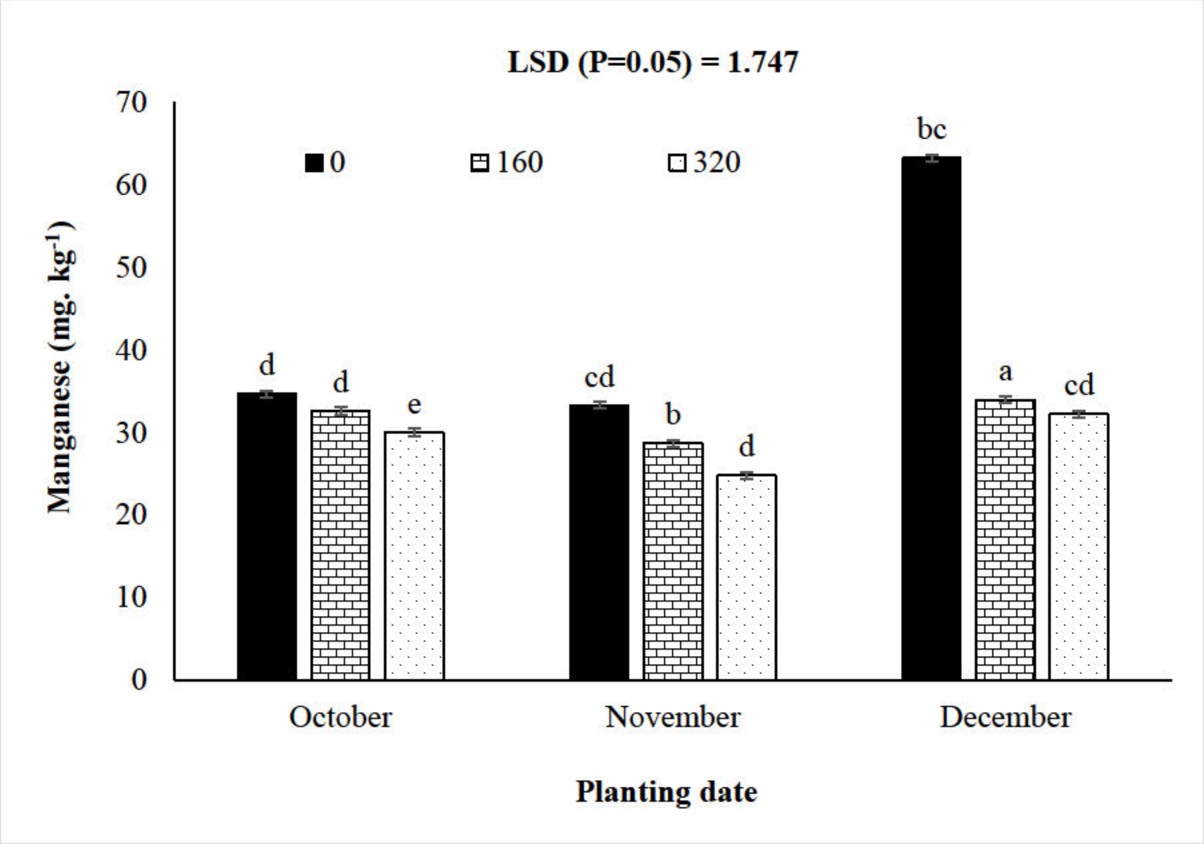

Figure 4.41: Effect of planting date Gromor Accelerator® application rate (0, 160 and 320 N kg ha^{-1}) averaged across landraces on the manganese of taro cormels under dryland field conditions.

The interaction of Gromor Accelerator® application rate and landrace (P<0.001) significantly affected manganese content at Ukulunga. Manganese content of MG and PI was only enhanced when 0 N kg per hectare of organic fertiliser was applied where MG was significantly higher than PI (Figure 4.42). However, the addition of 160 and 320 N kg per hectare of organic fertiliser significantly decreased manganese content of both MG and PI. The application of 0 N kg per hectare of organic fertiliser indicated PI with the highest (49.9 mg. kg^{-1}) manganese content compared to MG when 0, 160 and 320 N kg per hectare of organic fertiliser was applied.

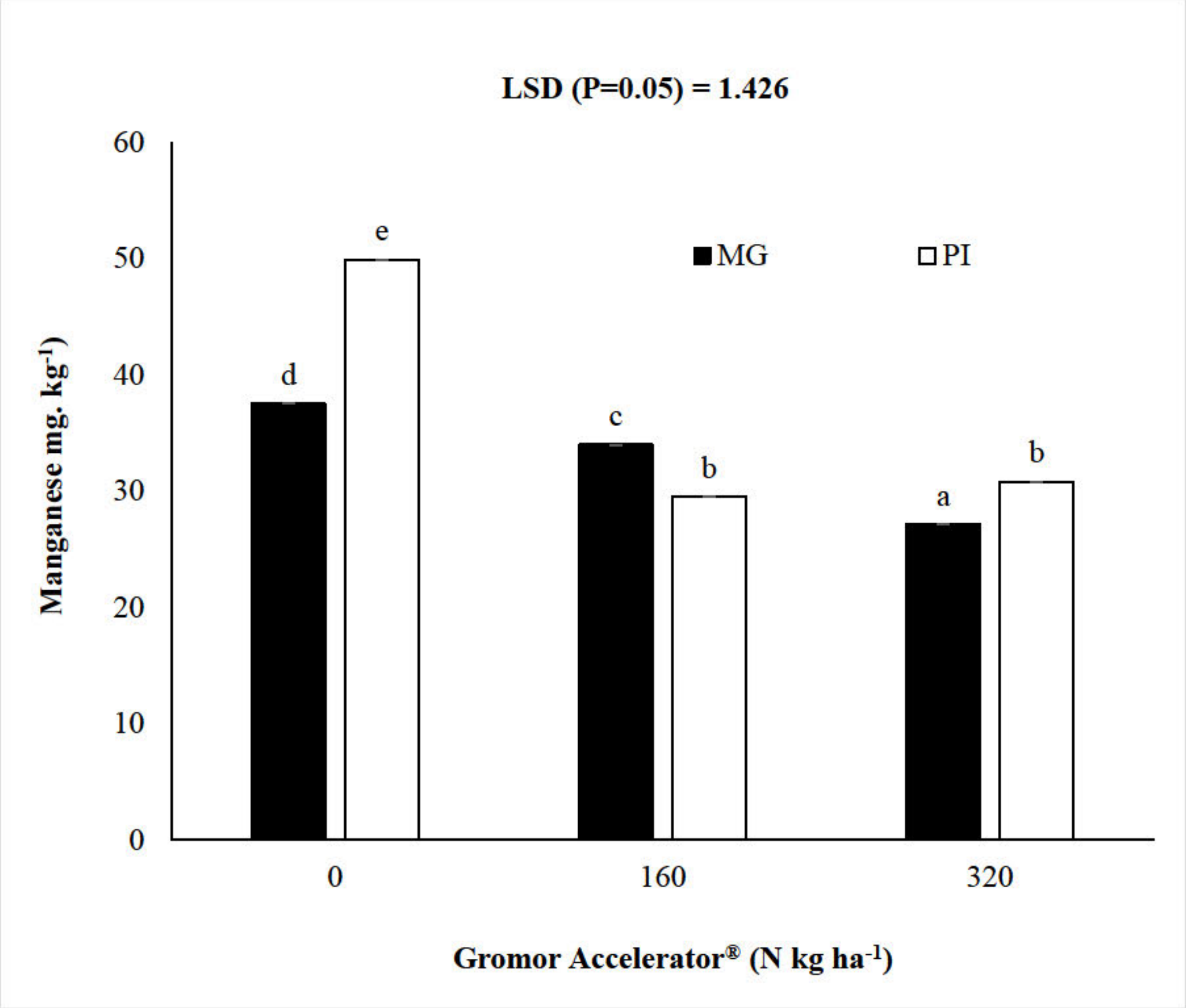

Figure 4.42: Effect of Gromor Accelerator® application rate and landraces (PI and MG) averaged across planting date on the manganese of taro cormels under dryland field conditions.

The interaction of planting date and landrace (P<0.001) significantly affected manganese content at Ukulunga. December planting obtained the highest manganese content for both MG and PI significantly higher than October and November planting (Figure 4.43). Delaying planting from October to November significantly decreased the manganese content of MG and PI. But a further delay in planting by two months significantly increased manganese content of

MG and PI, but PI was significantly higher than MG, where both landraces were not significantly different from each other. The lowest manganese content was obtained by MG when planting was done in November.

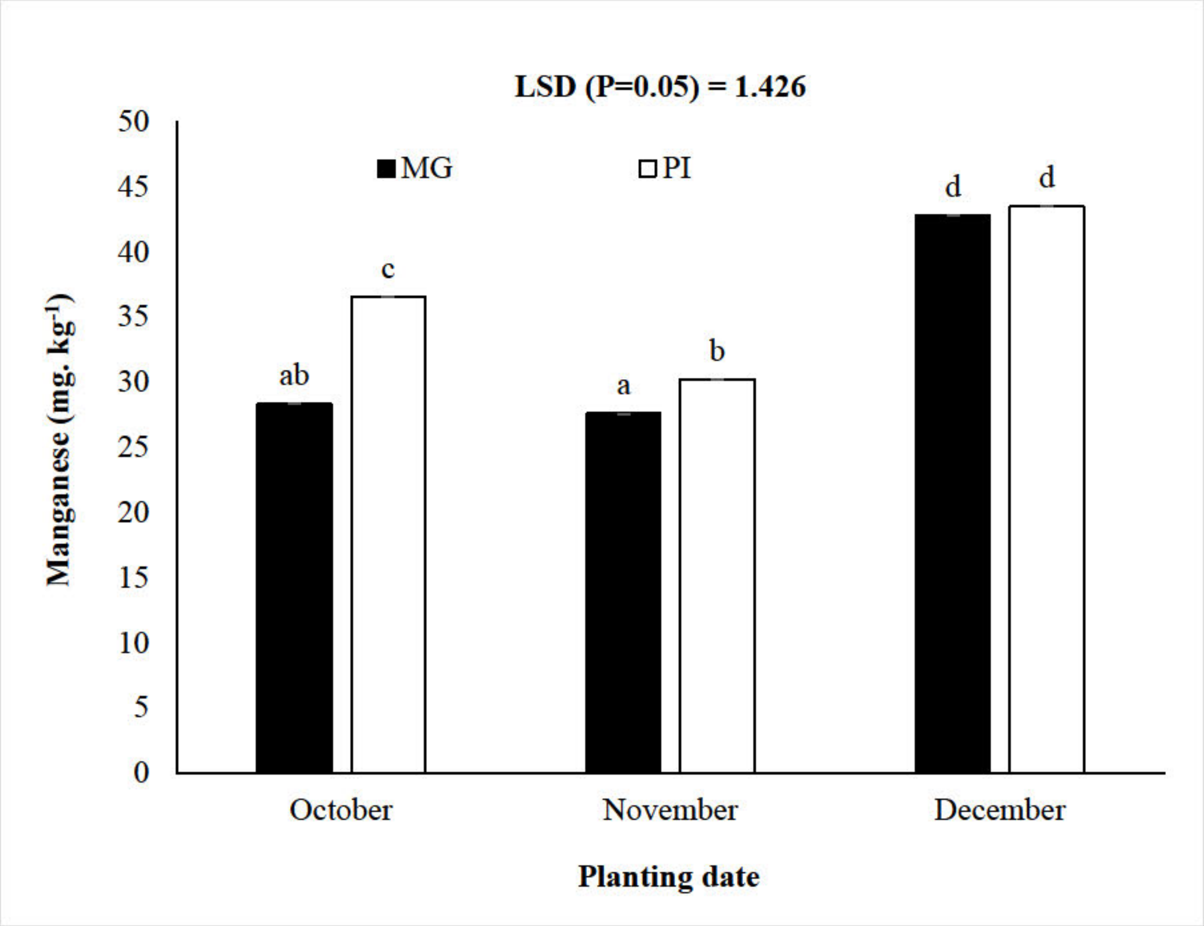

Figure 4.43: Effect of planting date and landraces (PI and MG) averaged across Gromor Accelerator® application rate on the manganese of taro cormels under dryland field conditions.

There was significant ($P<0.001$) interaction between planting date, landrace and Gromor Accelerator® application rate in the manganese content of taro corms at Ukulinga. When 0 N kg per hectare Gromor Accelerator® was applied, delaying planting from October to December significantly increased manganese content of PI, whereas delaying planting from October to November decreased manganese content of MG followed by an increase in December (Table 4.9). The highest manganese content of MG and PI was obtained with 0 N kg per hectare of Gromor Accelerator® than with 160 and 320 N kg per hectare organic fertiliser when planting was done in December. The addition of 160 N kg per hectare of organic fertiliser decreased magnesium content for PI and MG when planting was delayed by one month, followed by an increase when planting was further delayed until December. The application of 160 N kg per hectare of organic fertiliser showed PI not significantly different when planting was done in November and December. Further addition of 320 N kg per hectare of organic fertiliser showed MG with an increase in the manganese content of corms when planting was delayed from October to December, whereas for PI showed a decline in November planting, followed by an increase in December planting. PI and MG yielded the highest manganese content with the application rate of 0 N kg per hectare of organic fertiliser, but PI was significantly higher than MG.

Table 4.9: Effect of planting date and Gromor Accelerator® application rate on manganese (mg kg^{-1}) of taro cormels of different landraces under dryland field conditions. Means of the interaction effect within columns and rows followed by the same letter are not significantly different from each other.

Planting date	**Landraces**	**Gromor Accelerator® (N kg ha^{-1})**		
		0	**160**	**320**
October	MG	29.94cde	31.51de	23.41ab
	PI	39.35g	33.69ef	36.52fg
November	MG	25.33abc	30.1cde	27.26bcd
	PI	41.19g	27.15bcd	22.28a
December	MG	57.23h	40.28g	30.74de
	PI	69.16i	27.61bcd	33.62ef
LSD (P=0.05)				2.470

4.3.10.9 Sodium content

Delaying planting date, landraces, Gromor Accelerator® application rate and the interaction of planting date and Gromor Accelerator® application rate (P<0.001) were all highly significant in the sodium content of taro corms at Ukulinga. Delaying planting date from October to December increased the sodium content of taro corms when no fertiliser was applied (Figure 4.44). Application of 160 N kg per hectare of organic fertiliser significantly enhanced the sodium content when planting was done in November, whereas further increase of 320 N kg per hectare of organic fertiliser significantly increased sodium content in December. The addition of 320 N kg per hectare of organic fertiliser yielded the highest sodium content when planting was delayed until December, while the lowest was obtained with 0 N kg per hectare of organic fertiliser during October planting.

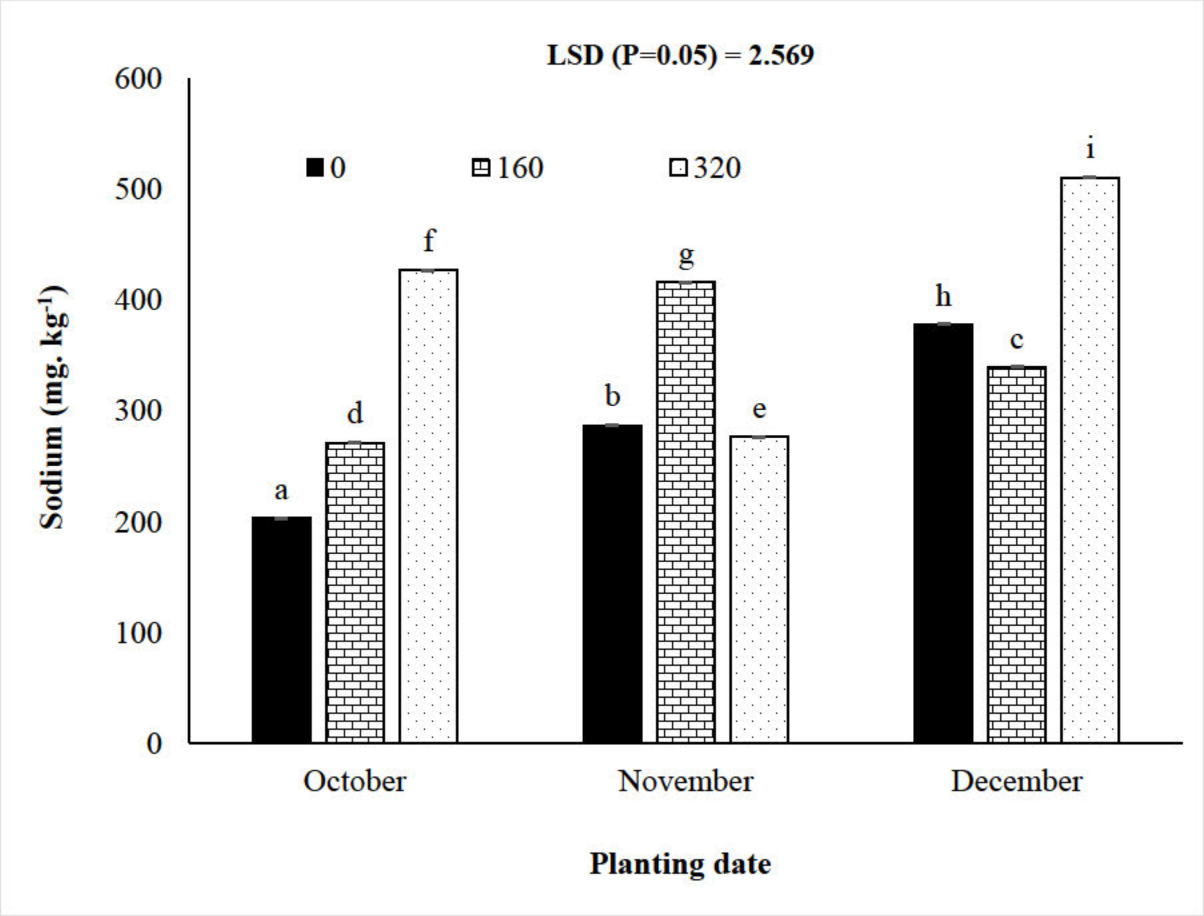

Figure 4.44: Effect of planting date and Gromor Accelerator® application rate (0, 160 and 320 N kg ha^{-1}) averaged across landraces on sodium of taro cormels under dryland field conditions.

The interaction of Gromor Accelerator® application rate and landraces (P<0.001) had significant effect on sodium content of corms at Ukulinga. Application of organic fertiliser increased the sodium content of MG and PI (Figure 4.45). The application of no fertiliser and 160 N kg per hectare of organic fertiliser showed MG with higher sodium content than PI.

However, when 320 N kg per hectare of organic fertiliser was applied, PI had the highest sodium content compared to MG. The lowest sodium content was achieved by PI when 0 N kg per hectare of organic fertiliser was applied.

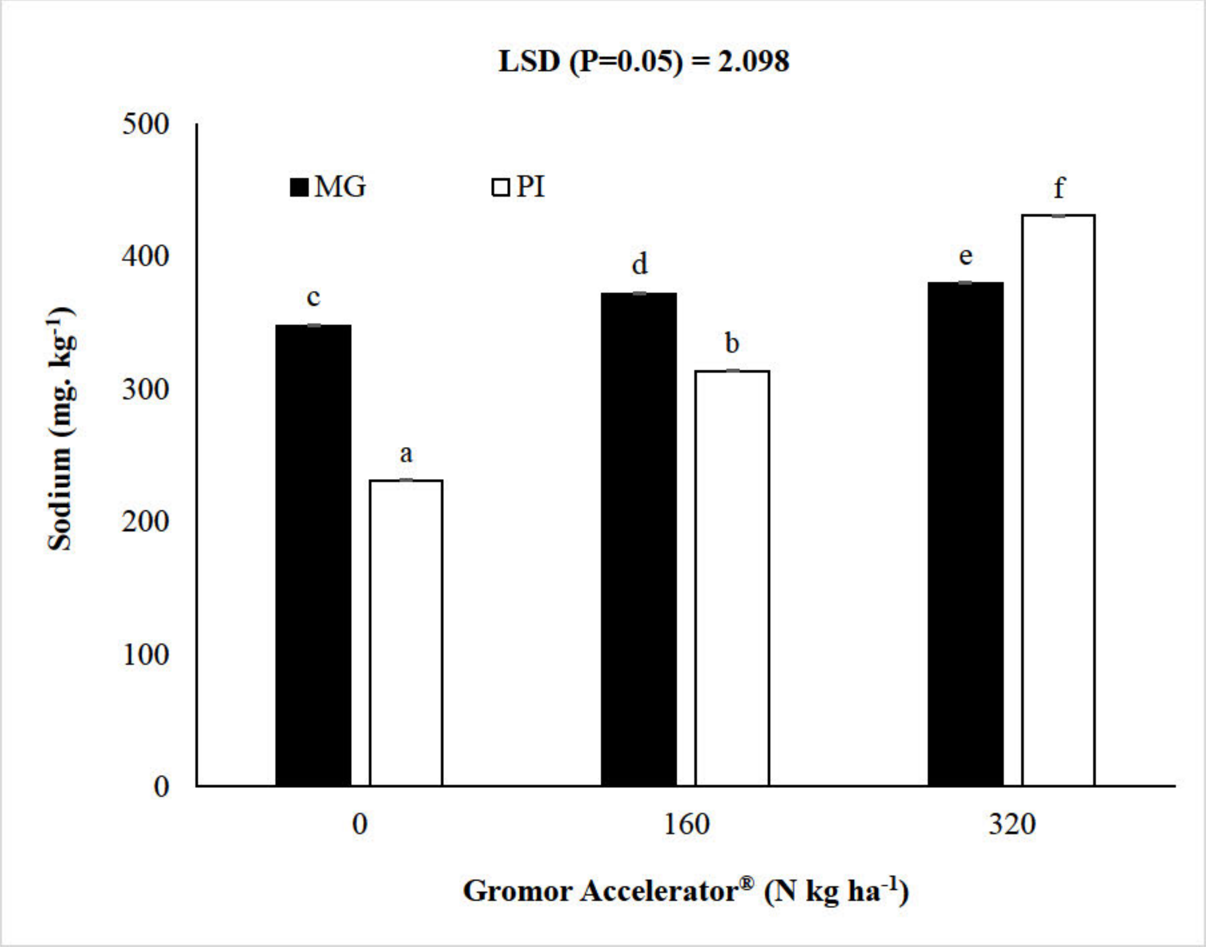

Figure 4.45: Effect of Gromor Accelerator® application rate and landraces (PI and MG) averaged across planting date on the sodium of taro cormels under dryland field conditions.

The interaction of planting date and landrace significantly affected the sodium content of corms at Ukulinga ($P<0.001$). Sodium content was increased for MG when planting was delayed by until November thereafter declined when planting was done in December (Figure 4.46). Delaying planting from October to November decreased the sodium content of PI, but a further delay to December significantly increased yielding the highest sodium content than other planting dates.

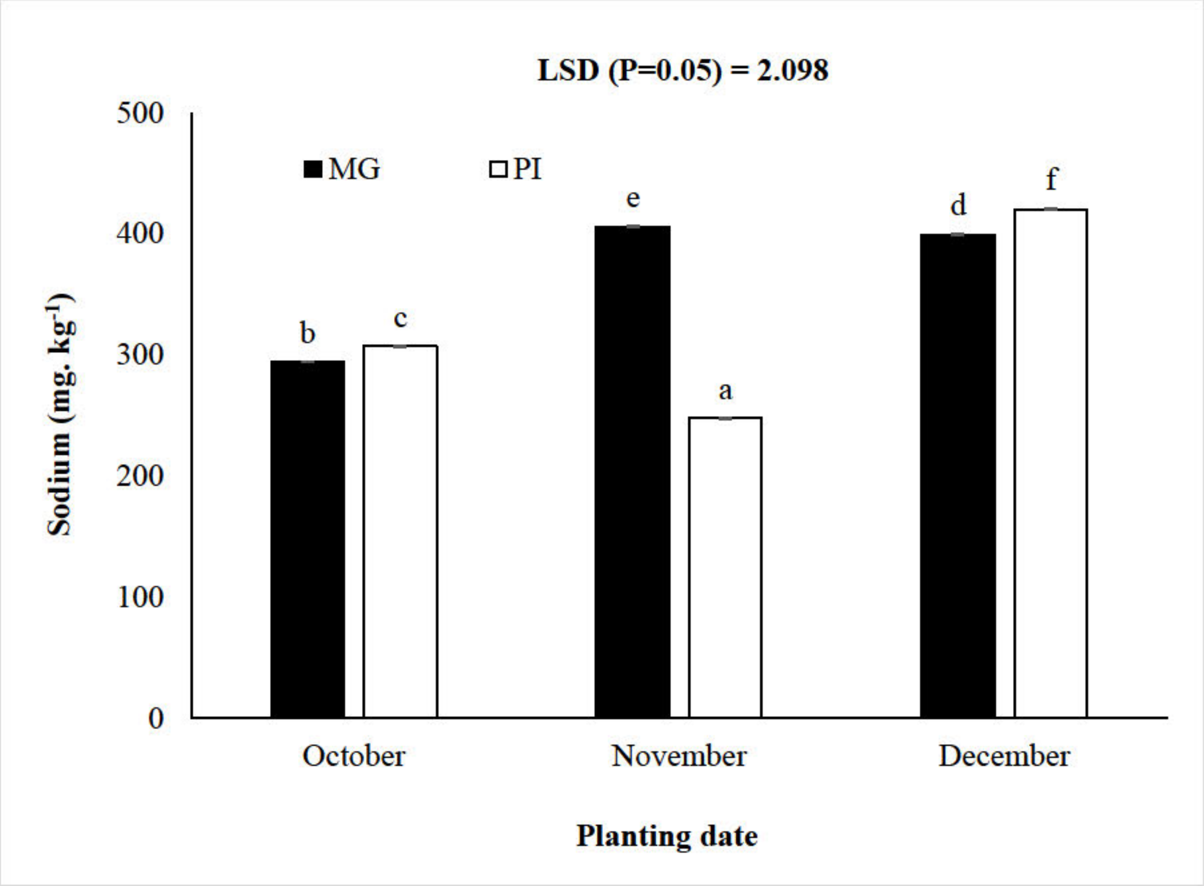

Figure 4.46: Effect of planting date and landraces (PI and MG) averaged across Gromor Accelerator® application rate on the sodium of taro cormels under dryland field conditions.

The interaction between planting date, landrace and Gromor Accelerator® application rate played a significant role in the sodium content of taro corms at Ukulinga ($P<0.001$). When no fertiliser was applied, delaying planting from October to December significantly increased the sodium content of both MG and PI, but MG significantly yielded higher sodium content than PI in October, November and December (Table 4.10). Addition of 320 N kg per hectare of organic fertiliser showed a decline in the sodium content of both landraces when planting was delayed by one month from October, then followed by an increase in the sodium content of MG and PI when planting was done in December. When 160 N kg per hectare of organic fertiliser was applied sodium content of PI was increased by delaying planting from October to December, whereas delaying planting until November increased sodium content for MG then decreased in December where PI was significantly higher than MG. The highest (543.16 mg kg^{-1}) sodium content was obtained by PI in October when 320 N kg per hectare of organic fertiliser was applied, whereas for MG, the highest (521.34 mg kg^{-1}) sodium content was obtained with 160 N kg per hectare of organic fertiliser when planting was done in November.

Table 4.10: Effect of planting date and Gromor Accelerator® application rate on sodium (mg kg^{-1}) of taro cormels of different landraces under dryland field conditions. Means of the interaction effect within columns and rows followed by the same letter are not significantly different from each other.

Planting date	**Landraces**	**Gromor Accelerator® (N kg ha^{-1})**		
		0	**160**	**320**
October	MG	239.41d	331.47g	311.94f
	PI	166.7a	211.46c	543.16l
November	MG	385.25h	521.34k	311.45f
	PI	189.18b	311.84f	242.36d
December	MG	418.96i	263.1e	516.12k
	PI	337.7g	416.89i	506.32j
LSD (P=0.05)				3.634

4.3.10.10 Phosphorus content

The phosphorus content of taro cormels was affected by delayed planting (P = 0.012) at Ukulinga. Fertiliser, landrace and all their interactions, as well as the interaction of planting date, landrace and Gromor Accelerator® application rate, were all not significant (P>0.05). Delaying planting from October to November significantly decreased phosphorus content of corms, whereas a further delay in planting to December showed a significant increase in phosphorus content (Figure 4.47). However, October and November planting were not significantly different from each other. December planting obtained the highest phosphorus content of corms than October and November planting, respectively.

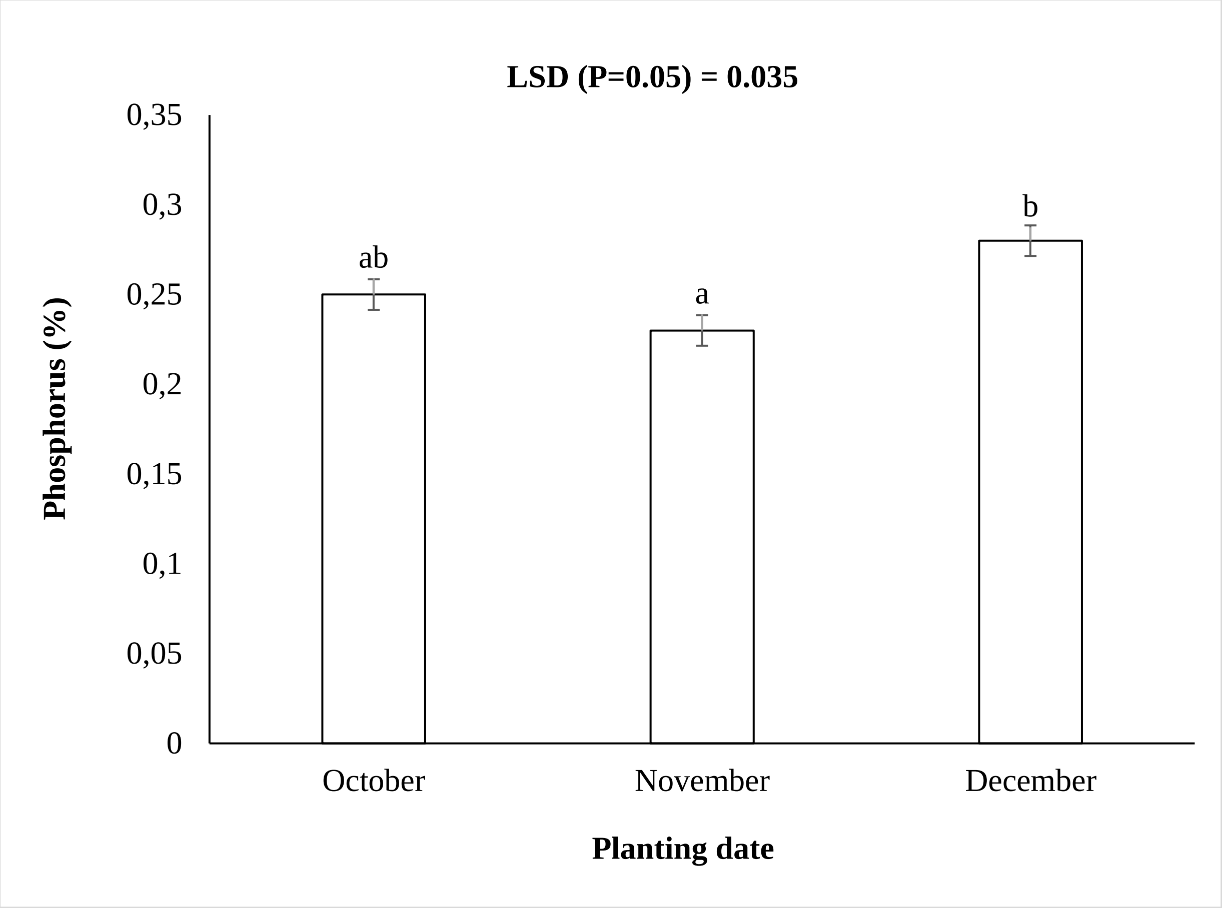

Figure 4.47: Effect of planting date averaged across Gromor Accelerator® application rate and landraces on phosphorus of taro cormels under dryland field conditions.

4.3.10.11 Total sulfur content

There was significant (P = 0.002) interaction between planting date, landrace and Gromor Accelerator® application rate in the sulfur content of taro corms at Ukulinga. Organic fertiliser (P = 0.043) and the planting date (P = 0.013) were observed to play a significant role in total sulfur content. Landrace and all the interactions of fertiliser and planting date; fertiliser and landrace, as well as planting date and landrace, were all observed not to be significant (P>0.05). Delaying planting from October to December significantly increased the total sulfur content of PI when no organic fertiliser was applied, where total sulfur content of MG decreased in November followed by an increased in December, where the total sulfur content of both MG and PI was not different for all planting dates (Table 4.11). The total sulfur content of MG and PI was significantly increased when planting was delayed by one and two months with 160 N kg per hectare of organic fertiliser, whereas additional of 320 N kg per hectare of organic fertiliser significantly increased MG with PI displaying a decrease in total sulphur content when planting was delayed from October to December. The addition of organic fertiliser displayed MG and PI as not different from each other when planting was done in October, November and December. However, MG yielded the highest total sulphur content with 320 N kg per hectare of organic fertiliser when planting was done in December, while PI showed higher total sulphur content with 0 N kg per hectare of organic fertiliser when planting was delayed by two months.

Table 4.11: Effect of planting date and Gromor Accelerator® application rate on sulphur (mg kg^{-1}) of taro cormels of different landraces at under dryland field conditions. Means of the interaction effect within columns and rows followed by the same letter are not significantly different from each other.

Planting date	**Landraces**	**Gromor Accelerator® (N kg ha^{-1})**		
		0	**160**	**320**
October	MG	0.132ab	0.104ab	0.106ab
	PI	0.122ab	0.102a	0.131ab
November	MG	0.112ab	0.11ab	0.113ab
	PI	0.126ab	0.113ab	0.114ab
December	MG	0.116ab	0.13ab	0.142b
	PI	0.137ab	0.124ab	0.11ab
LSD (P=0.05)				0.0197

4.3.10.12 Zinc content

Planting date, landraces, fertiliser and the interaction planting date and Gromor Accelerator® application rate (P<0.001) significantly affected zinc content of taro cormels at Ukulinga. Delaying planting by two months increased zinc content when 160 or 320 N kg per hectare of organic fertiliser was applied, obtaining higher zinc content than all other application rates (Figure 4.48). Application of no organic fertiliser increased zinc content of taro cormels when planting was done in October, whereas when planting was done in November, it was increased by adding 320 N kg per hectare of organic fertiliser. There were no differences between no organic fertiliser and 160 N kg per hectare of organic fertiliser when planting was delayed until November. The highest zinc content was displayed by December planting when 160 N kg per hectare of organic fertiliser was applied, whereas the lowest was obtained with October planting when 320 N kg per hectare of organic fertiliser was applied.

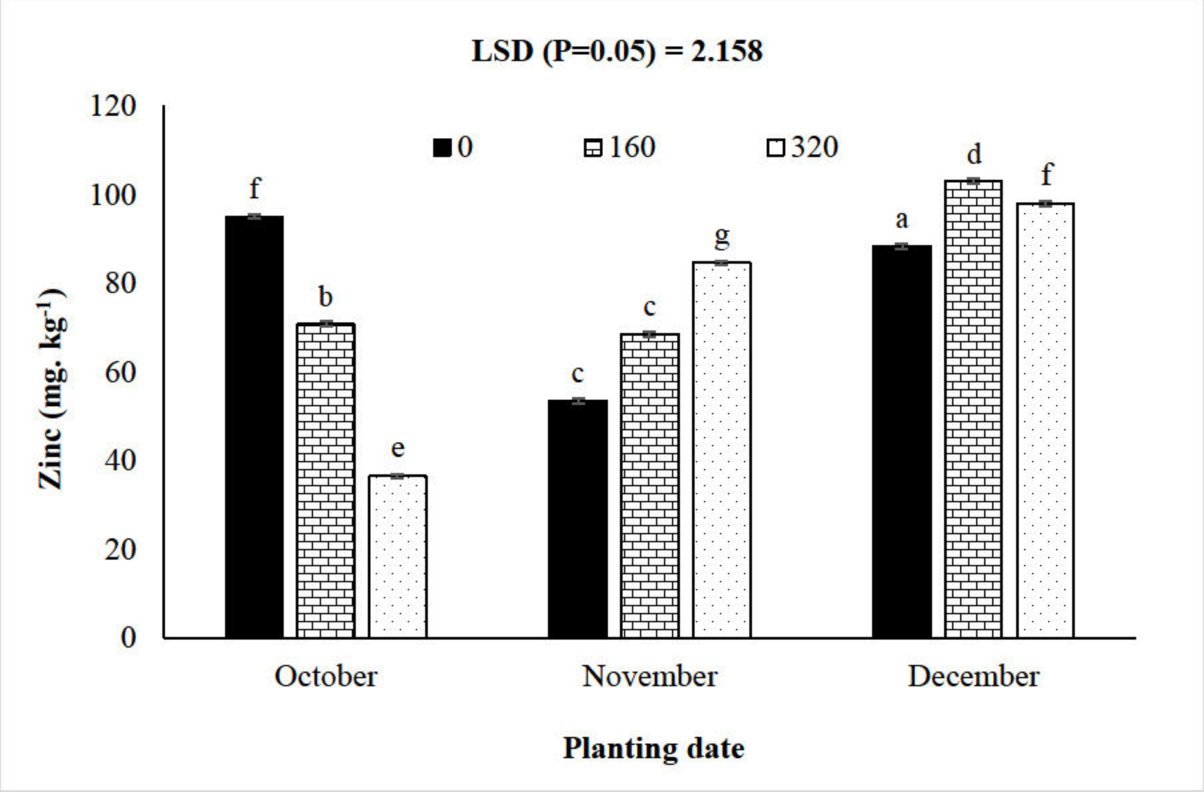

Figure 4.48: Effect of planting date and Gromor Accelerator® application rate (0, 160 and 320 N kg ha^{-1}) averaged across landraces on the zinc of taro cormels under dryland field conditions.

The interaction of Gromor Accelerator® application rate and landraces (P<0.001) had a significant effect on zinc content of taro corms at Ukulinga. Application of no fertiliser increased zinc content for PI higher than MG, but further increase of 160 and 320 N kg ha^{-1} of organic fertiliser decreased zinc content for PI (Figure 4.49). Adding 160 N kg per hectare of organic fertiliser enhanced zinc content for MG, whereas a further increase of 320 N kg per hectare significantly decreased the zinc content of taro corms. PI yielded the highest zinc content with 0 N kg per hectare of organic fertiliser while MG had the lowest zinc content when 0 N kg per hectare was applied.

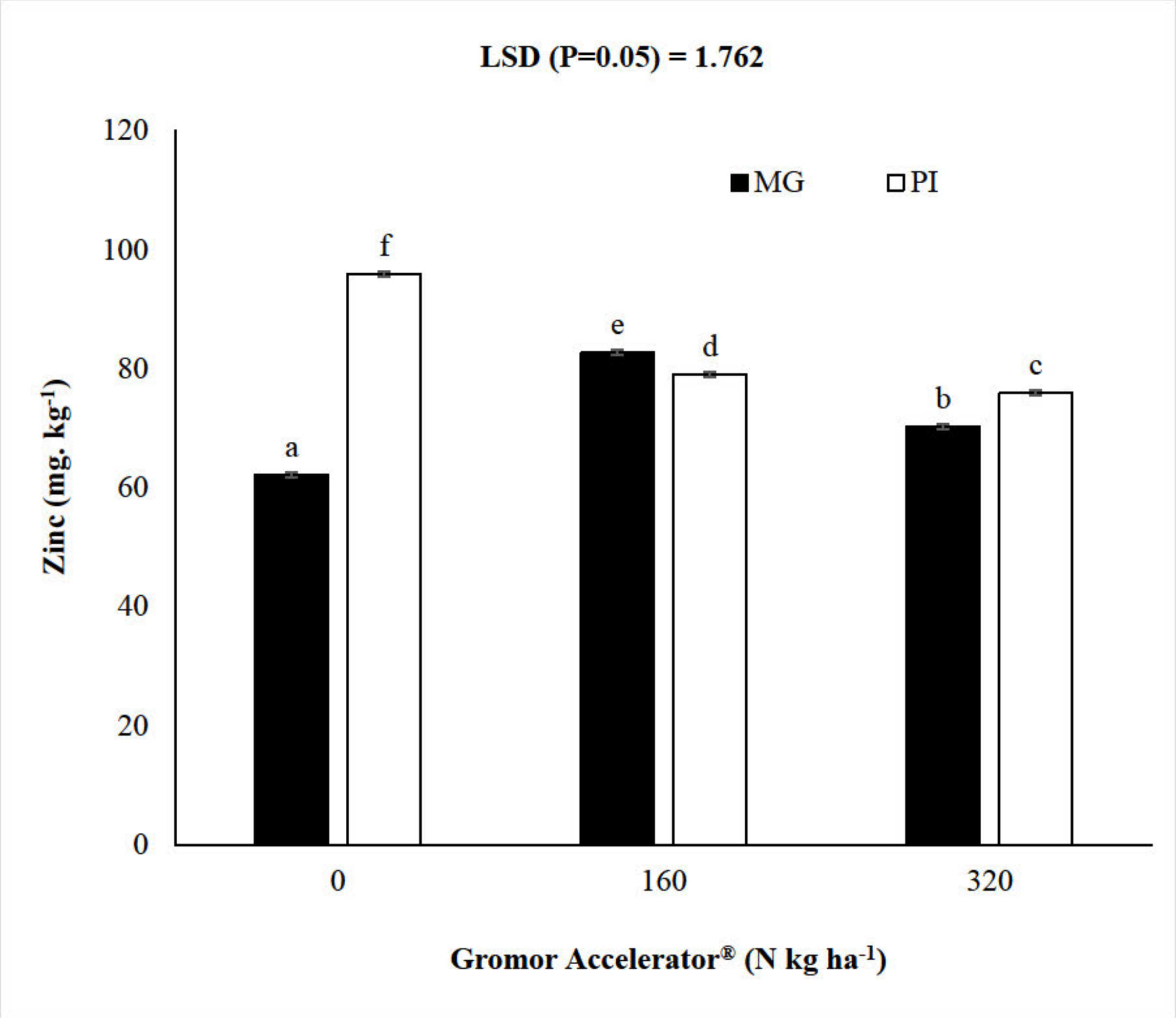

Figure 4.49: Effect of Gromor Accelerator® application rate and landraces (PI and MG) averaged across planting date on the zinc of taro cormels under dryland field conditions.

The zinc content of taro cormels was significantly ($P<0.001$) affected by the interaction of planting date and landrace at Ukulinga. Delaying planting from October to November significantly decreased zinc content of PI followed by increase when planting was done in December, whereas for MG, zinc content was significantly increased by delaying planting from October to December (Figure 4.50). The lowest zinc content was obtained by MG with October planting, whereas the highest zinc content was obtained by MG when planting was done in December.

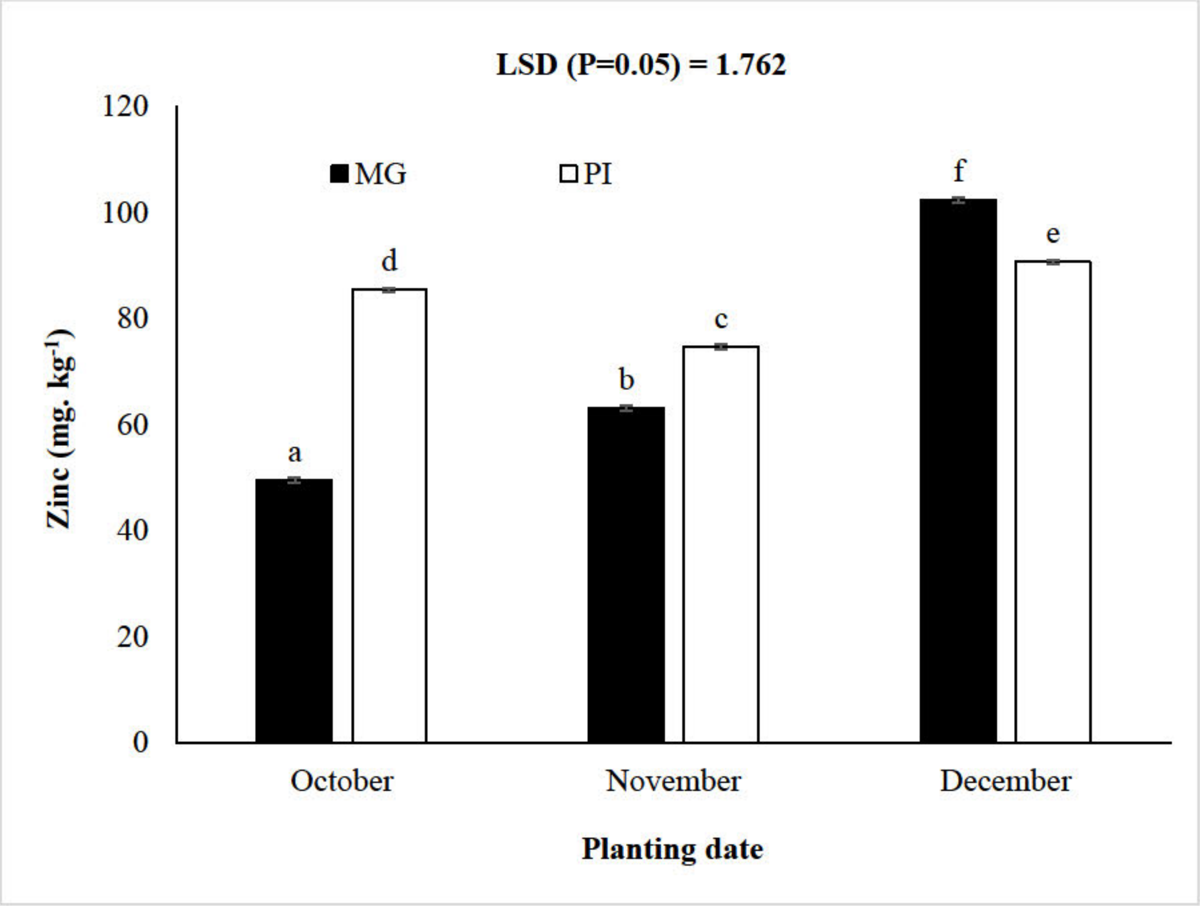

Figure 4.50: Effect of planting date and landraces (PI and MG) averaged across Gromor Accelerator® application rate on the zinc of taro cormels under dryland field conditions.

The interaction of planting date, landrace and Gromor Accelerator® application rate positively affected the zinc content of taro corms at Ukulinga ($P<0.001$). Delaying planting from October to November decreased zinc content of MG and PI when no fertiliser was applied, thereafter increased when planting was delayed by two months for both MG and PI where PI displayed no difference when planted in November and December (Table 4.12). Applying 160 N kg per hectareof organic fertiliser significantly increased zinc content of MG when planting was delayed from October to December, whereas for PI zinc content was decreased when planting was done in November then increased again when planting was done in December. Further addition of 320 N kg per hectare of organic fertiliser when planting was delayed from October to December significantly increased the zinc content of MG and PI, where there was no different effect between MG and PI planted in October. The highest zinc content was obtained by MG with 160 N kg per hectare of organic fertiliser compared to 320 N kg per hectare of organic fertiliser, while the lowest was obtained by MG in November with no organic fertiliser.

PI indicated the highest zinc content when planting was done in October with 0 N kg per hectare of organic fertiliser.

Table 4.12: Effect of planting date and Gromor Accelerator® application rate on zinc (mg. kg^{-1}) of taro cormels of different landraces under dryland field conditions. Means of the interaction effect within columns and rows followed by the same letter are not significantly different from each other.

Planting date	**Landraces**	**Gromor Accelerator® (N kg ha^{-1})**		
		0	**160**	**320**
October	MG	70.68d	41.09b	36.9b
	PI	119.53i	100.64h	36.07b
November	MG	23.32a	85.2ef	80.89e
	PI	83.69ef	51.94c	88.4fg
December	MG	92.33g	121.7i	93.03g
	PI	84.55ef	84.39ef	103.08h
LSD (P=0.05)				3.052

4.3.11 Feed moisture and starch content

There were significant differences (P<0.001) between Gromor Accelerator® application rate, planting date and landraces together with their interactions with respect to moisture and starch content. However, there was no significant difference among the landraces (P>0.05) with respect to moisture content. The interaction of the Gromor Accelerator® application rate and planting date indicated a high significance (P<0.001) in moisture and starch content. The application of no organic fertiliser significantly enhanced moisture content for late November planting then decrease when planting was delayed by two months where there was a difference between November and December planting (Table 4.13). When the planting was delayed by one and two months, moisture content of taro corms was significantly decreased compared to early planting when 160 N kg per hectare of organic fertiliser was applied, where November and December were not different. Further application of 320 N kg per hectare of organic fertiliser enhanced the moisture content of October planting more than December and November, respectively. Delaying planting from October to December significantly increased starch content when no organic fertiliser was applied where no difference was indicated between December and November when 0 and 320 N kg per hectare of organic fertiliser was applied (Table 4.13). Addition of 160 and 320 N kg per hectare of organic fertiliser significantly increased starch content when planting was delayed by one month from October followed by a decrease in December. October planting with 320 N kg per hectare of organic fertiliser indicated the highest moisture content with the lowest obtained by October with no organic fertiliser, whereas two months delay in planting yielded the highest starch content without organic fertiliser and lowest was obtained by October when 160 N kg per hectare of organic fertiliser was applied.

Table 4.13: Effect of Gromor Accelerator® application rate and planting date averaged across landrace on feed moisture and starch content under dryland field conditions. Means of the interaction effect within columns and rows followed by the same letter are not significantly different from each other.

Gromor Accelerator® (N kg ha^{-1})	**Planting date**	**Feed moisture content (%)**	**Feed starch content (%)**
0	October	62.59a	60.30c
	November	65.88bcde	67.67ef
	December	65.28bc	72.20g
160	October	68.14de	38.12a
	November	65.87bcde	70.12fg
	December	65.70bcd	67.12e
320	October	68.16e	54.09b
	November	63.86ab	70.85g
	December	67.38cde	63.18d
LSD (P=0.05)		1.439	1.519

The interaction of Gromor Accelerator® application rate and landraces showed significant differences (P<0.001) on moisture content. Application of organic fertiliser enhanced the moisture content of MG when 160 or 320 N kg per hectare of organic fertiliser was applied, whereas for PI increase was indicated with 160 N kg per hectare of organic fertiliser thereafter decreased when 320 N kg per hectare of organic fertiliser was applied (Table 4.14). There was no difference between MG and PI when no organic fertiliser and 160 and 320 N kg per hectare of organic fertiliser was applied. The starch content was observed to be high in PI (67.74%) and MG (65.71%) when fertiliser was not applied but observed with a decrease when 160 N kg per hectare of organic fertiliser was applied and increased again with 320 N kg per hectare of organic fertiliser (Table 4.14). Overall, MG and PI yielded the highest moisture content with 320 and 160 N kg per hectare of organic fertiliser respectively, whereas, for starch content, MG and PI obtained the highest with 0 N kg per hectare of organic fertiliser compared to 160 and 320 N kg per hectare of organic fertiliser.

Table 4.14: Effect Gromor Accelerator® application rate and landrace averaged across planting date on feed moisture and starch content under dryland field conditions. Means of the interaction effect within columns and rows followed by the same letter are not significantly different from each other.

Gromor Accelerator® (N kg ha^{-1})	**Landraces**	**Feed moisture content (%)**	**Feed starch content (%)**
0	MG	64.69a	65.71c
160		66.11ab	54.89a
320		67.24b	61.01b
0	PI	64.48a	67.74d
160		67.02b	62.02b
320		65.70ab	64.40c
LSD **(P=0.05)**		1.175	1.241

The interaction of planting date and landraces played a significant role with respect to moisture content ($P<0.001$) at Ukulinga. A significant decrease in moisture content was displayed by MG when planting was done in November and December, whereas for PI delaying planting by one month decreased moisture content and then increased with December planting where October and November were not different from each other (Table 4.15). October planting yielded the lowest starch content for MG and PI, whereas delaying planting by one month increased starch content for both landraces followed by a decrease when planting was further delay to December (Table 4.15). Delaying planting by two months significantly showed no difference between the landraces. However, PI obtained the highest moisture content in December significantly higher than of MG, but delaying planting by one month significantly displayed the highest starch content for MG compared to PI

Table 4.15: Effect of planting date rate and landrace averaged across Gromor Accelerator® application rate on feed moisture and starch content under dryland field conditions. Means of the interaction effect within columns and rows followed by the same letter are not significantly different from each other.

Planting date	**Landraces**	**Feed moisture content (%)**	**Feed starch content (%)**
October	MG	68.20c	42.82a
November		66.23b	70.97d
December		63.61a	67.82c
October	PI	64.40a	58.85b
November		64.18a	68.13c
December		68.63c	67.18c
LSD (P=0.05)		1.175	1.241

The interaction of planting date, landraces and Gromor Accelerator® application rate was displayed to play a significant role with respect to moisture and starch content ($P<0.001$). Delaying planting by one and two months significantly decreased moisture content for MG, where for PI, it was increased by delaying planting from October to December when organic fertiliser was not applied and there was no difference between MG and PI when planting was done in November (Table 4.16). Adding 160 N kg per hectare of organic fertiliser increased and decreased moisture content of MG and PI in November planting, respectively, followed by a decrease in December for MG but an increase for PI, whereas landraces showed no difference in moisture content when planted in November and December. Further increase in organic fertiliser of 320 N kg per hectare decreased moisture content of MG and PI in November thereafter increased with two months delay in planting where no significant difference was observed between landraces when planted in November and December. The starch content for MG and PI was significantly increased when planting was delayed by one and two months with 0 N kg per hectare of organic fertiliser (Table 4.16). But when organic fertiliser of 160 or 320 N kg per hectare was applied, the starch content for MG and PI significantly increased when planting was delayed until November then decreased when planting was delayed by two months from October, respectively. There was no difference in starch content between MG and PI by delaying planting until November when 320 N kg per hectare of organic fertiliser was applied. The application no organic fertiliser significantly displayed the highest (73.39%) starch content for PI when planting was delayed by two months, whereas the lowest (20.68%) was obtained by MG with October planting when 160 N kg per hectare of organic fertiliser was applied.

Table 4.16: Effect Gromor Accelerator® application rate, planting date and landrace on feed moisture and starch content under dryland field conditions. Means of the interaction effect within columns and rows followed by the same letter are not significantly different from each other.

Gromor Accelerator® (N kg ha^{-1})	**Planting date**	**Landraces**	**Feed moisture content (%)**	**Feed starch content (%)**
0	October	MG	66.93def	57.43cd
	November		65.96cde	68.68 ghij
	December		61.17ab	71.02 ijk
160	October		67.17def	20.68a
	November		68.98ef	72.52jk
	December		62.19abc	71.47 ijk
320	October		70.50f	50.37b
	November		63.74bcd	71.70ijk
	December		67.48def	60.98de
0	October	PI	58.25a	63.16ef
	November		65.80cde	66.66fgh
	December		69.39ef	73.39k
160	October		69.10ef	55.57c
	November		62.76bc	67.72 ghi
	December		69.21ef	62.77ef
320	October		65.83cde	57.82cd
	November		63.98bcd	70.01hijk
	December		67.29def	65.38fg
LSD **(P=0.05)**			2.035	2.149

4.4 Discussion

The objective of the study was to investigate the effect of planting date, and fertilisation on growth, development, and yield quality of taro landraces *Umgingqeni* and *Pitshi* found in Umbumbulu, KwaZulu-Natal under field environmental conditions. The emergence of taro plants varied with planting date, landrace type and the application rate of organic fertiliser. The results showed that one-month delay in planting had a high emergence at Ukulinga compared to other planting dates used in the study. This result may be explained by the fact that, possibly in the period of early planting dates, there was enough water supply and moisture in the soil with ideal temperatures than later planting dates. The research study by Horton (1987), Ali (1989) and Mare (2009) also found that environmental conditions such as water availability and temperature should be adequately available in the soil during planting to ensure proper taro emergence. The SWC was relatively higher during early planting October, followed by one and two months delay in planting dates, and that concludes October planting to have received more water than the two late planting dates. Hence, November and October obtained better crop stand count emergence than the December planting. Therefore, it was concluded that the time of planting and fertilisation of taro are classified as vital factors affecting crop growth performance in agronomic related practises issues (Mare, 2009). In some studies, Wadas *et al.* (2004) and Hagman *et al.* (2009) reported that nitrogen fertilisation impacted negatively on time of emergence for tuber plants.

Warmer environmental conditions are known to cause an increase in the number of leaves per plant (Almekinders and Struik, 1996; Mare, 2009). The present finding also supports a study by Mare (2006), which concluded that the variation in leaf number per plant shown between the taro landraces in the present study was more characterised by the difference within genotypes and that some landraces produced more suckers than others while others did not produce any sucker. Results of the leaf number measured at Ukulinga indicated a significant difference between the planting date and organic fertiliser level. The final leaf number was higher at early planting October followed by two months delay in planting, with November planting obtaining the lowest. The result is consistent with findings of past studies by Nanda *et al*. (1995) that early planting date results in an increase in leaf number per plant of brassica species compared to same species that were planted in late planting dates. However, on the other hand, organic fertiliser application enhanced leaf number per plant where an increase in organic fertiliser of 320 N kg per hectare obtained the highest final leaf number followed by 160 N kg per hectare then lastly 0 N kg per hectare of organic fertiliser. These observations could possibly suggest that plants at high fertiliser level were able to receive adequate growth resources more than at low and no fertiliser levels. It is suggested that plants are grown at low and no fertiliser level were competing for resources and their leaves senescence early to contribute to corm formation in the form of escaping stress.

Results of plant height measured at Ukulinga showed that delaying planting date and the application of organic fertiliser had an influence on taro landraces. Taller plants were recorded in October and December planting when the rainfall was relatively high. These findings confirm the statement made by Zrust (1995) that plants exposed to water stress conditions tend to have short plant height. Plant height is also considered to be sensitive to drought conditions and that plants exposed to low water stress conditions tend to be tallest (Deblonde and Ledent, 2001; Alsharari *et al*., 2007; Mare, 2009). *Mgingqeni* was observed with the tallest plants compare to *Pitshi* landrace. This could be influenced by the fact that the planting material for *Mgingqeni* relatively has larger corm size, whereas *Pitshi* is characterised with small corm in size. However, all taro landraces followed the same trend of increase in plant height until they reached a maximum after then declined. Application of organic fertiliser enhanced the plant height, where the optimum organic fertiliser level of 320 N kg per hectare had tallest plants followed by a low organic fertiliser level of 160 N kg per hectare and the no fertiliser level with the shortest plants over time. These findings confirm a statement by Allison *et al*. (1999) and Mare (2009), that plant height is influenced by organic fertiliser application rate. Also mentioned by Mondal and Sen (2005) that the eddoe type of taro its plant height increased at the increasing rate of fertiliser level.

The result of the leaf area showed that early planting dates significantly affected leaf area with October obtaining higher leaf area per plant as compared to the late planting dates November and December. Similar reports were mentioned by Mare (2009) that planting dates significantly affected leaf area. A possible explanation for this is that environmental conditions experienced during the early planting date, which could be higher rainfall and ideal temperatures. The finding is consistent with the results of past studies by Bussell and Bonin (1998), and Rinaldi (2003), that early planting dates are characterised of experiencing ideal weather conditions for planting. Drought is reported to be associated with a reduced leaf area plant^{-1} (Ojala *et al*., 1990). Another study by Jefferies (1992) mentioned that drought had reduced the final leaf size of all the potato genotypes studied. However, he concluded that the size of the effect differed with respect to genotype. In this study, it was shown that the application of organic fertiliser and no fertiliser only enhanced the early planting date more than the late planting dates. That may also have influenced the yield for early planting to be higher than of the two late planting dates through that plants were able to absorb maximum interception of light with successive vegetative growth. Results showed *Mgingqeni* landrace having larger leaf area per plant than

Pitshi landrace, and this is caused by that *Mgingqeni* is characterised as having large seed corm than *Pitshi*, which is naturally small in seed corm size. These findings concur with Stahlschmidt *et al*. (1997) and Mare (2009), who reported that large gloves used as planting material during early planting dates resulted in larger leaf areas in garlic hence, indicating the effect of corm size on plant leaf area.

Chlorophyll content index is characterised as an indicator of the photosynthetic capacity of plant tissue (Nayyar and Gupta, 2006; Alabi, 2015). Chlorophyll content plays a significant role as the index used in estimating plant nutrition conditions (Zhao *et al*., 2011). The results of CCI showed that November planting had the highest CCI, followed by early planting date October, lastly two months delay in planting December. This was an indication that delaying planting dates by further two months could result in a decrease in CCI. This might be the cause that taro eventually reaches maturity stage, and at this stage, it is the process of a rapid decline in shoot growth as well as total shoot dry weight resulting in a decline in the number of active leaves (Sibiya, 2015). During this stage, the crop reaches the maturity stage with the leaf also approaching the senescence period where the corm size continues to increase, while root and shoot growth decline (Sivan, 1982; Sibiya, 2015). Silva *et al*. (2008) reported that plants become reduced when leaf development decreases in intensity.

Planting date was highly significant with respect to photosynthetic active radiation (PAR). One-month delay in planting date obtained the highest PAR below and above compared to early planting date followed by December planting, but significant variation was not observed among other planting dates November and December. This could be caused by that two months delay in planting had more weeds than early and one- month delay in planting, which resulted in more shading effect of crops and weeds reducing light intensity within the crop as well as the reduction in biomass production. This finding is similar to the results reported by Macanawai *et al*. (2012) that more weeds resulted in a shading effect and reducing biomass production (Sibiya, 2015). Sweet potato experiencing drought stress conditions is reported to likely to result in low photosynthesis in the form of reducing chlorophyll 'a' fluorescence, stomatal conductance as well as intercellular carbon dioxide (CO_2) through stomatal closure (Van Heerden and Laurie, 2008). In severe drought conditions chlorophyll 'a' and 'b' are reported to be sensitive, resulting in a reduction of both chlorophyll a and b together with total chlorophyll under severe water stress conditions (Bray, 2002; Blum, 2009; Motsa *et al*., 2015).

Such reduction is reported to be caused by leaf senescence and a decline of water use in plants resulting in an increase in electrolyte leakage (Bray, 2002).

In this study, the SC was relatively higher for late planting December relative to early planting October and November planting, respectively. Results of SC showed that sensitivity of stomatal closure to planting date and application of organic fertiliser was landrace dependent, with *Pitshi* being the most sensitive than *Mgingqeni*. This finding agrees with a study reported by Dwelle *et al*. (1981) and Alabi (2015) that genotypic differences could be the main factor causing differences among white yam as well as to other root and tuber crops with respect to stomatal regulation. The research study by Alabi (2015), also reported that a decrease in stomatal conductance over time could be influenced by a decrease in temperature as well as a decrease in relative humidity over time. For Gromor Accelerator® application rate, the stomatal closure was more sensitive on 0 N kg per hectare, followed by 160 N kg per hectare with 320 N kg per hectare achieving high stomatal conductivity. The application of organic fertiliser 320 N kg per hectare indicated high maintenance of stomatal conductance than 160 N kg per hectare and 0 N kg per hectare, respectively. As results, the conditions were better favourable for 320 N kg per hectare as demonstrated by its greater display of stomatal control, making it more suitable for production. Environmental conditions are characterised with the change from time to time, and that might not always be favourable for crop growth (Alabi, 2015). Plant species need to adjust and adapt well to achieve effective tolerance under unfavourable weather conditions for optimum crop growth and yield (Xue-Xuan *et al*., 2010; Mabhaudhi *et al*., 2013). The regulation opening and closing of stomata is mainly influenced by relative humidity, which enables water loss from the plant in the process of transpiration and photosynthesis (Bareja, 2011; Alabi, 2015). A reduction in stomatal conductance is reported with a negative effect on biomass accumulation and also limits the plant's ability to integrate fully the level of carbon dioxide (Ocheltree *et al*., 2014).

Yield components (biomass, corm mass and corm number) recorded at Ukulinga displayed a similar trend on taro landraces when planted at different planting dates with the application of organic fertiliser. In this study, the biomass kg per plant, cormel mass kg per plant, and the number of cormels per plant were highest at earlier planting date October compared to delayed planting dates, since early planting was characterised to experience ideal weather conditions higher rainfall and temperature. This was confirmed by Miyasaka *et al*. (2003); that time of planting had an effect on taro crop growth when it was planted in Spring and Summer by achieving the highest corm fresh weight compared to the taro that was planted during Winter and fall plantings. In terms of taro landraces, *Mgingqeni* obtained the highest biomass kg per plant, cormel mass kg per plant and number of cormels per plant under early planting date compared to *Pitshi* but then decreased with delayed planting. Previous studies by Sangakkara (1993), Scheffer *et al.* (2005) and Mare (2009), also reported that Sweet potatoes planted in Spring and Summer during the period of high rainfalls relative to Winter and fall plantings during the plant growth season automatically produced the highest yields. The Gromor Accelerator® application rate only enhanced the biomass kg per plant, cormel mass kg per plant, and the number of cormels per plant of the early planting date October then decreased with delayed planting dates November and December. An early increase in leaf growth through higher rainfall and temperatures may have attributed to an increase in cormel mass during the early planting date. Previous studies have reported that the application of 100 to 150 kg ha^{-1} of nitrogen significantly increased the yield (O'Beirne and Cassidy, 1990). However, some studies reported that nitrogen fertilisation had a minor effect on yield with the application of phosphorus and potassium responding positively with increased yields (Wadas *et al.*, 2004; Hagman *et al.*, 2009).

Overall, *Mgingqeni* had a better HI for October and November planting compared to *Pitshi*, where no difference was shown between landraces when planting was done in October, November and December. A study done in Taiwan by Lu *et al*. (2001) stated that January and March plantings significantly yielded the highest final harvest index in taro, due to high temperatures throughout crop growth stage experienced by these plantings whereas the lowest was achieved by July and September plantings, which was believed to be caused by declining temperatures during crop growth stage when the crops were planted in July and September. Delaying planting from October to November when 160 N kg per hectare of organic fertiliser was applied increased HI of *Mgingqeni* than *Pitshi*, whereas a further delay in planting decreased HI of both landraces, where no difference was displayed between landraces when planting was done in October, November and December. However, when 320 N kg per hectare of organic fertiliser was applied HI significantly indicated an increase for *Mgingqeni* than *Pitshi* in November, while a further delay by two months in planting showed an increase in HI for *Pitshi* only, but a decrease for *Mgingqeni* where landraces were not different in October and November planting.

The yield was observed to vary significantly with planting dates. Overall, the actual yield kg per hectare was higher for the early planting date October, while yield components decreased with delay in planting dates and improved with the application of organic fertiliser and varied between taro landraces *Mgingqeni* and *Pitshi*. This result is in line with our alternative hypothesis that the different planting dates, and organic fertiliser application rate will influence the final yield of taro landrace. Results for the actual yield kg per hectare showed *Mgingqeni* to be significantly higher than *Pitshi* during October and November planting. Mare (2009), reported that suitable planting dates are characterised as those that do not affect other stages of crop growth as the crop experiences severe moisture stress nor unfavourable temperature conditions to minimise severe damages on yield and crop quality. Results indicated that applying organic fertiliser increased the actual yield kg per hectare then when planting was delayed, whereas the highest actual yield kg per hectare was obtained by October planting with the application of 160 N kg per hectare of organic fertiliser where October and November were not significantly different. Previous studies have indicated that applying organic fertiliser when planting taro would lead to increasing yields of taro (Mare, 2009). The study showed that the application of organic fertiliser increased the yields of taro landraces, and this was also translated to growth parameters where applying organic fertiliser had more effect on the early planting date than late planting dates. The results match those observed in previous studies on sweet potatoes planted during the high amount of rainfall in October obtained the highest yields due to adequate amount of rainfall and temperature, allowing the crop to receive its valuable nutrients during crop growth (Sangakkara 1993; Kumar *et al*., 2007; Hagman *et al*., 2009; Mare,2009).

The results of the mineral elements indicated significant differences between the planting date, organic fertiliser and landraces and these included; aluminium, boron, calcium, copper, iron, potassium, magnesium, manganese, sodium, phosphorus, total sulphur and zinc content except for carbon and nitrogen content of taro cormels from Ukulinga. This shows that the planting date, landrace and organic fertiliser had an influence on the accumulation of minerals of taro cormels. Previous studies have indicated planting date, fertilisation, cultivar and environmental conditions as key factors influencing the corm quality (Mare, 2009). The results were consistent with the alternative hypothesis of the study as the planting date, landrace and organic fertiliser influenced the mineral content of taro cormels. As reported by Kader and Rolle (2004), and Mare (2009) that fertilisation has a great effect on the water and nutrient supply transported to the plant, which automatically influences the harvested yield and nutritional quality. The application of organic fertiliser was found not to have an effect on the nitrogen content of taro cormels at Ukulinga. However, interestingly, this is contrary to a study conducted by Colla *et al*. (2005) and Mare (2009), where it was reported that increasing the application of fertiliser resulted in an increase in nitrogen content of tubers. The mineral elements were significantly increased by an increase in organic fertiliser application rate, and similar findings were reported by El-Sirafy *et al.* (2008) that application of farmyard manure resulted in a significant increase in the mineral content such as, potassium, phosphorus and nitrogen content of the potato tubers gravity (El-Sirafy *et al*., 2008).

Delaying planting by two months when no organic fertiliser was applied significantly increased starch content for *Pitshi* whereas *Mgingqeni* decreased when planting was done early in October with organic fertiliser. The moisture content of *Pitshi* was significantly increased by delaying planting with two months than *Mgingqeni*, but delaying planting until November significantly increased the starch content for *Mgingqeni* compared to *Pitshi*. Overall, *Mgingqeni* and *Pitshi* yielded the highest moisture content with an increase in organic fertiliser, whereas, for starch content, *Mgingqeni* and *Pitshi* obtained the highest without the use of organic fertiliser compared to the increase of organic fertiliser. The variation of starch content within taro landraces may be confirmed from the findings by Will *et al*. (1983) and Mare (2009) that genetic variation plays a significant role in the influence of starch properties in taro. As mentioned from the literature that starch content is one of the key components which influences corm quality for the production of crisp chips in taro (O`Keefe *et al.*, 2005). A study by Mare (2009), reported that the starch content was negatively influenced by delaying the planting date at Ukulinga, where *Dumbe-dumbe* and *Pitshi* had a decrease in starch content with delayed planting date. According to literature, higher rainfall experienced during early planting date, mainly the stage of corm bulking characterised with decreasing temperatures towards crop maturity, results in high starch content in potatoes provided that moisture content is adequately available in the soil (Smith, 1987; Mare, 2009). Reported from the literature that the starch content in potato tubers plays a significant role in the texture of crisps and that for better quality crisping the starch content ideal range should not be less than 15% and the starch content investigated in the study was found to be in the ideal range for the quality of crisp (Kita, 2002).

4.5 Conclusion

The purpose of the current study was to determine the effect of planting date and fertilisation on growth development, and yield quality of taro landraces, where the results indicated planting date and organic fertiliser to have a significant effect on growth development and yield quality of *Mgingqeni* and *Pitshi* at Ukulinga. The results obtained from the study suggest that there is a potential benefit of growing these two taro landraces during October, November and December planting at KZN. Taro crop establishment, growth parameters, final yield and yield parameters, mineral content as well as the starch and moisture content were significantly affected by planting date and organic fertiliser amount where the response differed with landraces at Ukulinga. Taro growth and yield parameters decreased with delay in planting and were positively affected by increasing the application rate of organic fertiliser. The final yield, including the mineral composition of taro, is mainly affected by planting date and organic fertiliser application rate; however, the response varies with landraces. Overall, *Mgingqeni* performed better than *Pitshi*, in terms of growth parameters and yield parameters particularly when planting was done in October with the application rate of 160 N kg per hectare of organic fertiliser. There is a greater need for understanding and expand knowledge on agronomic practices, including environmental conditions, which are controlling the production of taro landraces that is necessary for maximising productivity. Therefore, to maximise and improve taro crop establishment, growth parameters, final yield and yield parameters, mineral content including starch and moisture content, it is recommended that taro is planted during early planting dates compared to late planting dates at Ukulinga.

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CHAPTER 5

GENERAL CONCLUSION AND RECOMMENDATIONS

5.1 General discussion

In Sub-Saharan Africa (SSA) region, a continuous increase in population has resulted in a significant challenge in food security (Alabi, 2015). The growing population and limited resources have placed a lot of pressure, mainly for smallholder agriculture, to be able to deliver food security. The issue of water scarcity has caused significant severe effects on challenges the world is facing today. Major issues such as rapid increase in population and climate change variability, have exerted more pressure on future food security and impacting negatively on water-scarce countries like South Africa (Alabi, 2015). Thus, South Africa continues to experience a major increase in food insecurity even though the country is declared food secure at the national level, whereas in the rural areas the conditions have been identified as very poor and food insecure (van der Berg, 2006; Abdu-Raheem and Worth, 2011; Shisana *et al*., 2013; Walsh and Van Rooyen, 2015).

Diversification of previously neglected and underutilised crop species (NUCS) has been suggested as a possible future crop solution to the impending threat of food insecurity, and that could yield positive results through broadening the food basket and improving the current situation of food production (Mabhaudhi, 2012; Modi and Mabhaudhi, 2013). South Africa is known as one of the driest countries in the world resulting to suffering from malnutrition where dependence for a living is mainly on food such as cereals, grain legumes and a narrow range of root and tuber crops [Irish potato (*Solanum tuberosum*)], sweet potato (*Ipomoea batatas*) and taro (*Colocasia esculenta*)] (Allermann *et al*., 2004; Wenhold *et al*., 2012; Alabi, 2015). However, decades of negligence by researchers and farmers in the cultivation of these major crops have indicated that more studies need to be done on agronomy, and water-use of NUS since their information describing agronomy and water-use exists in limited quantities.

Root and tuber crops are regarded as one of the essential staple foods after cereals and grain legumes feeding more than 20% world's population (Mare, 2009; Alabi, 2015). Root and tuber crops have been proven to be rich in micronutrients and carbohydrates. However, they remain under-explored in the country (Mare, 2006). There is a growing demand to reintroduce neglected underutilised root and tuber crops in order to diversify crop production and increase food basket, especially within semi-arid and arid tropics that are characterised as water-scarce with poor soil fertility that is limiting agriculture. Taro is still considered as one of the staple foods that play a vital role in food security since it has high value of (energy, carbohydrate, fibre, vitamins, calcium, iron, and dietary supplement) and also has low levels of fat (Mare, 2006; Lewu *et al*., 2010; Naidoo *et al*., 2015).

In this study, it was hypothesised that the application of different water levels and different planting dates would have an influence on the final yield and nutrition of underutilised local taro landraces (*Colocasia esculenta* L. Schott). To test this hypothesis, two landraces were selected for the field experiment *Mgingqeni* and *Pitshi* under field environmental conditions, whereas a single taro landrace *Umbumbulu* was selected for the control environment experiment under varying water treatments. Under control environment experiment a single landrace was selected because limited availability of the taro landraces.

5.2 Challenges

- Aphids attacked taro plants both in the Control environment facility and field environment experiments; however, they were controlled through spraying with insecticides, but they kept on coming back.

5.3 Future lessons and research possibilities

The following recommendations are based on the observations made during the study to improve the promotion of the crop;

- These findings provide insights for future research to consider planting in a different site environment that is within or outside the province to improve the yield of taro landrace.
- A future study investigating the intercropping of taro landraces with other crops such as cereals, legumes, and other root crops would be interesting.
- Considerably more taro landraces, including foreign genotype, should be investigated for future studies on water use and nutritional productivity, since the study only focused on *Umbumbulu, Mgingqeni*, and *Pitshi* for control and field experiment.
- For future studies, it would be highly useful to investigate other factors of experimental data, such as agronomy management practices e.g. planting density in order to evaluate the effect on yield and quality for a variety of taro landraces.

Chapter 2 evaluated the review of literature; it was shown that taro is a vital crop with very high nutritional benefits and dietary supplements. However, these characteristics prove that the crop has good values in agricultural production. Improvement in the state of food security and income generation could result in low levels of poverty and hunger in the world. Through the improvement of agronomic management practices such as best selection on landrace and optimum planting densities, including a better understanding of crop water use for yield and quality, taro production stands a good chance of improving food production in most of the Sub-Saharan Africa (SSA) countries.

Chapter 3 evaluated the growth and response of taro to different irrigation regimes under controlled environmental conditions. A single taro landrace *Umbumbulu* was used for the study. The results showed that water stress negatively impacted the plant growth and yield, with SWC being significantly high under optimum water conditions relative to limited water conditions. This was observed by slow and uneven emergence, stunted growth and suppressed physiology under limited water conditions (30% ETa) than in optimum water conditions (100% ETa). Growth parameters for *Umbumbulu* (plant height, leaf area per plant, leaf number, SC and CCI) under limited water conditions were observed to be lower relative to optimum water conditions. But chlorophyll fluorescence was higher under water stress conditions relative to optimum water conditions. Underwater stress conditions taro matured earlier than well-watered conditions demonstrating drought escape through phenological plasticity. Overall, *Umbumbulu* landrace had higher yield and yield parameters (biomass, corm mass, corm number, and HI) under optimum water conditions, while WUE, NC and NWP were all high under limited water conditions. In addition, *Umbumbulu* landrace was shown to have higher starch content under optimum water conditions compared to limited water conditions. The ability of taro plants to maintain photosynthetic capacity under optimum water conditions relative to water stress conditions was the reason for high starch content.

Chapter 4 investigated the effect of planting date and fertilisation on growth, development and yield of taro landraces under field conditions. Two taro landraces *Mgingqeni* and *Pitshi* were used for the study. The findings reported in Chapter 4 of this study indicate that the actual yield and yield components were in line with the explanations of development and growth parameters. The results show that there were statistically significant differences due to planting date and organic fertiliser on crop establishment, growth parameters, actual yield and yield parameters, mineral, starch and moisture content measured at Ukulinga. Crop establishment of taro landraces was high during November, followed by October and December planting, respectively. Growth parameters (leaf number, leaf area and plant height), SC, CCI, PAR and SWC were positively affected by delayed planting and positively affected by the application of organic fertiliser at Ukulinga. Both landraces performed better when they were planted in the early planting date, whereas a further delay in planting indicated fewer or no differences at all.

Yield varied in taro landraces with planting dates where the actual yield and yield parameters and HI were significantly high during early planting date then increased through the addition of organic fertiliser. Higher yields were due to better emergence and strong plant growth occurred in the early planting, which was also characterised to have received better rainfalls and temperatures. *Mgingqeni* had significantly higher yield and yield parameters than *Pitshi,* so it was concluded that *Mgingqeni* performed better perhaps this was caused by that *Mgingqeni* has larger corm size, whereas *Pitshi* has small corm in size. Planting date and fertilisation had a significant effect on aluminium, boron, calcium, copper, iron, potassium, magnesium, manganese, sodium, phosphorus, total sulphur and zinc content except for carbon and nitrogen content of taro cormels. Mineral elements of taro landraces mentioned above were significantly increased by delaying the planting date when the application rate of 160 and 320 N kg ha^{-1} of organic fertiliser was applied at Ukulinga. The moisture content of taro landraces was found to be increased by organic fertiliser when planting was delayed, whereas the starch content was found to be increased by no organic fertiliser when planting was delayed. High starch content when planting was delayed could be the result of the plant to maintain well photosynthetic capacity, which accounts for optimum production.

Based on the study findings, it is better suggested that *Mgingqeni* and *Pitshi* landraces should be planted during early planting, which is October with the application rate of 160 and 320 N kg ha^{-1} of organic fertiliser to harvest higher yields at Ukulinga. Whereas *Umbumbulu* landrace under controlled environmental conditions is better planted under optimum water conditions for higher yields and starch content, but for high WUE, NC and NWP *Umbumbulu* must be planted under water stress conditions. To make underutilised taro landraces more favourable as well as attracting for commercial farming, more breeding efforts is required in order to maximise yields. The study findings with respect to agronomy management practices and water use of taro landraces could be useful to farmers to improve precise decision making on choosing the best taro landrace. Especially,deciding on planting date and fertilisation as well as water use on improving yield parameters and quality of taro production in order to add a positive value to South African food production which could prove to minimise food insecurity and hunger.

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APPENDICES

Appendix 1: Analysis of variance tables for Chapter 3

Control Environment Facility (CEF)

Growth parameters

Variate: Emergence (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	100.92	50.46	1.44	
Reps.*Units* stratum					
CWR	1	3285.44	3285.44	93.88	<.001
WAP	10	110255.58	11025.56	315.05	<.001
CWR.WAP	10	3061.34	306.13	8.75	<.001
Residual	42	1469.86	35.00		
Total	65	118173.14			

Variate: Plant height (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	2025.43	1012.72	89.88	
Reps.*Units* stratum					
CWR	1	4681.30	4681.30	415.46	<.001
WAP	34	66413.29	1953.33	173.35	<.001
CWR.WAP	34	1184.08	34.83	3.09	<.001
Residual	138	1554.97	11.27		
Total	209	75859.06			

Variate: Leaf area plant^{-1} (cm^2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	641276.	320638.	60.71	
Reps.*Units* stratum					
CWR	1	1986076.	1986076.	376.02	<.001

WAP	34	17799039.	523501.	99.11	<.001
CWR.WAP	34	774479.	22779.	4.31	<.001
Residual	138	728897.	5282.		
Total	209	21929767.			

Variate: Leaf number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	3.9238	1.9619	10.12	
Reps.*Units* stratum					
CWR	1	26.7857	26.7857	138.22	<.001
WAP	34	220.6476	6.4896	33.49	<.001
CWR.WAP	34	18.3810	0.5406	2.79	<.001
Residual	138	26.7429	0.1938		
Total	209	296.4810			

Variate: CCI (µmol m^{-2})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	73.95	36.97	2.69	
Reps.*Units* stratum					
CWR	1	70.88	70.88	5.15	0.025
WAP	34	4035.75	118.70	8.62	<.001
CWR.WAP	34	1315.44	38.69	2.81	<.001
Residual	138	1900.23	13.77		
Total	209	7396.24			

Variate: CF (3500 µmol m^{-2} s^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.004667	0.002333	0.96	
Reps.*Units* stratum					
CWR	1	0.001714	0.001714	0.71	0.402
WAP	34	1.001238	0.029448	12.12	<.001

CWR.WAP	34	0.168286	0.004950	2.04	0.002
Residual	138	0.335333	0.002430		
Total	209	1.511238			

Variate: SC (mmol m^{-2} s^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	742.8	371.4	1.83	
Reps.*Units* stratum					
CWR	1	14743.8	14743.8	72.53	<.001
WAP	34	327395.3	9629.3	47.37	<.001
CWR.WAP	34	32966.5	969.6	4.77	<.001
Residual	138	28053.9	203.3		
Total	209	403902.2			

Variate: SWC (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	176.381	88.190	16.61	
Reps.*Units* stratum					
CWR					
	1	2140.811	2140.811	403.22	<.001
WAP	34	1374.580	40.429	7.61	<.001
CWR.WAP	34	365.631	10.754	2.03	0.002
Residual	138	732.673	5.309		
Total	209	4790.075			

Yield and yield parameters

Variate: Biomass (kg)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	2.2755	1.1377	5.70	
Reps.*Units* stratum					

CWR	1	9.3633	9.3633	46.89	<.001
Residual	44	8.7870	0.1997		
Total	47	20.4258			

Variate: Corm mass (kg)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.73376	0.36688	3.82	
Reps.*Units* stratum					
CWR	1	5.96994	5.96994	62.24	<.001
Residual	44	4.22064	0.09592		
Total	47	10.92434			

Variate: Number of corms

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	222.17	111.08	3.92	
Reps.*Units* stratum					
CWR	1	1621.69	1621.69	57.28	<.001
Residual	44	1245.62	28.31		
Total	47	3089.48			

Variate: Yield (kg. ha $^{-1}$***)***

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	2.265E+09	1.132E+09	3.82	
Reps.*Units* stratum					
CWR	1	1.843E+10	1.843E+10	62.24	<.001
Residual	44	1.303E+10	2.961E+08		
Total	47	3.372E+10			

Variate: Harvest Index (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Reps stratum	2	610.77	305.38	5.93	
Reps.*Units* stratum					
CWR	1	2422.20	2422.20	47.03	<.001
Residual	44	2266.11	51.50		
Total	47	5299.08			

Variate: WUE (kg. ha^{-1} mm^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	36398.	18199.	8.61	
Reps.*Units* stratum					
CWR	1	21110.	21110.	9.98	0.003
Residual	44	93026.	2114.		
Total	47	150533.			

Variate: WP (kg. m^{-3})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	108.782	54.391	7.16	
Reps.*Units* stratum					
CWR	1	19.993	19.993	2.63	0.112
Residual	44	334.063	7.592		
Total	47	462.838			

Nutritional content

Variate: Al (mg. kg^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	10.150	5.075	3.06	
Reps.*Units* stratum					
CWR	1	824.891	824.891	497.34	0.002
Residual	2	3.317	1.659		

Total	5	838.359

Variate: Ca (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.0005602	0.0002801	1.56	
Reps.*Units* stratum					
CWR	1	0.0098032	0.0098032	54.65	0.018
Residual	2	0.0003587	0.0001794		
Total	5	0.0107222			

Variate: Cu (mg. kg^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1.74783	0.87391	11.65	
Reps.*Units* stratum					
CWR	1	1.58611	1.58611	21.14	0.044
Residual	2	0.15009	0.07505		
Total	5	3.48403			

Variate: Fe (mg. kg^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	20.454	10.227	3.78	
Reps.*Units* stratum					
CWR	1	2109.458	2109.458	779.80	0.001
Residual	2	5.410	2.705		
Total	5	2135.322			

Variate: Mg (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.0007953	0.0003976	1.75	
Reps.*Units* stratum					
CWR	1	0.0040345	0.0040345	17.71	0.052

Residual	2	0.0004555	0.0002278		
Total	5	0.0052853			

Variate: Na (mg. kg^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	97.68	48.84	4.59	
Reps.*Units* stratum					
CWR	1	30185.54	30185.54	2839.47	<.001
Residual	2	21.26	10.63		
Total	5	30304.48			

Variate: Total N (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.22238	0.11119	3.89	
Reps.*Units* stratum					
CWR	1	1.39835	1.39835	48.91	0.020
Residual	2	0.05718	0.02859		
Total	5	1.67791			

Nutritional water productivity

Variate: NWP$_{Al}$ (mg. m^{-3})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	269412.	134706.	6.13	
Reps.*Units* stratum					
CWR	1	638059.	638059.	29.05	<.001
Residual	44	966510.	21966.		
Total	47	1873981.			

Variate: NWP$_{Ca}$ (m^{-3})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Reps stratum	2	1.1286	0.5643	4.07	
Reps.*Units* stratum					
CWR	1	6.2804	6.2804	45.28	<.001
Residual	44	6.1027	0.1387		
Total	47	13.5117			

Variate: NWP$_{Fe}$ (mg. m^{-3})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	423700.	211850.	5.90	
Reps.*Units* stratum					
CWR	1	1445212.	1445212.	40.26	<.001
Residual	44	1579495.	35898.		
Total	47	3448407.			

Variate: NWP$_{K}$ (m^{-3})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	70.99	35.49	2.60	
Reps.*Units* stratum					
CWR	1	122.69	122.69	8.97	0.004
Residual	44	601.73	13.68		
Total	47	795.41			

Variate: NWP$_{Mg}$ (m^{-3})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1.1994	0.5997	3.79	
Reps.*Units* stratum					
CWR	1	3.3230	3.3230	20.99	<.001
Residual	44	6.9670	0.1583		
Total	47	11.4894			

Variate: NWP$_{Mn}$ (mg. m^{-3})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1246.5	623.2	1.61	
Reps.*Units* stratum					
CWR	1	4595.3	4595.3	11.85	0.001
Residual	44	17068.4	387.9		
Total	47	22910.1			

Variate: NWP$_{Na}$ (mg. m^{-3})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	10062600.	5031300.	6.44	
Reps.*Units* stratum					
CWR	1	23590173.	23590173.	30.20	<.001
Residual	44	34371891.	781179.		
Total	47	68024664.			

Variate: NWP$_P$ (m^{-3})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1.1517	0.5759	0.58	
Reps.*Units* stratum					
CWR	1	4.9242	4.9242	4.96	0.031
Residual	44	43.7236	0.9937		
Total	47	49.7996			

Variate: NWP_Total$_N$ (m^{-3})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	32.510	16.255	1.86	
Reps.*Units* stratum					
CWR	1	732.658	732.658	83.72	<.001
Residual	44	385.049	8.751		
Total	47	1150.217			

Variate: NWP$_{Total\ S}$ (m^{-3})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	1.14897	0.57448	8.96	
Reps.*Units* stratum					
CWR	1	1.70971	1.70971	26.66	<.001
Residual	44	2.82141	0.06412		
Total	47	5.68008			

Feed Starch and Moisture

Variate: Feed Starch (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	5.7336	2.8668	3.18	
Reps.*Units* stratum					
CWR	1	81.4017	81.4017	90.21	0.011
Residual	2	1.8046	0.9023		
Total	5	88.9399			

Variate: Feed moisture (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	17.633	8.817	3.30	
Reps.*Units* stratum					
CWR	1	36.902	36.902	13.83	0.065
Residual	2	5.336	2.668		
Total	5	59.872			

Appendix 2: Analysis of variance tables for Chapter 4

Dryland Field Experiment (Ukulinga)

Growth parameters

Variate: Emergence (%)

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
PD	2		29290.	14645.	11.17	<.001
Landrace	1		1754.	1754.	1.34	0.248
FL	2		6717.	3358.	2.56	0.078
PD.Landrace	2		191.	96.	0.07	0.930
PD.FL	4		3580.	895.	0.68	0.604
Landrace.FL	2		249.	124.	0.09	0.910
PD.Landrace.FL	4		2471.	618.	0.47	0.757
Residual	1115		1462124.	1311.		
Total	1132		1506318.			

Variate: Leaf number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	9.246	4.623	3.71	0.025
Landrace	1	1.636	1.636	1.31	0.252
FL	2	25.228	12.614	10.14	<.001
PD.Landrace	2	0.739	0.370	0.30	0.743
PD.FL	4	2.559	0.640	0.51	0.725
Landrace.FL	2	2.073	1.036	0.83	0.435
PD.Landrace.FL	4	2.372	0.593	0.48	0.753
Residual	1332	1657.573	1.244		
Total	1349	1701.426			

Variate: Plant height (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	45372.1	22686.0	111.33	<.001
Landrace	1	2009.3	2009.3	9.86	0.002
FL	2	5322.7	2661.3	13.06	<.001
PD.Landrace	2	220.7	110.3	0.54	0.582
PD.FL	4	972.2	243.0	1.19	0.312
Landrace.FL	2	36.4	18.2	0.09	0.915
PD.Landrace.FL	4	33.6	8.4	0.04	0.997
Residual	1332	271431.6	203.8		
Total	1349	325398.5			

Variate: Leaf area plant^{-1} (cm^{2})

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
PD	2		13231160.	6615580.	66.26	<.001
Landrace	1		828073.	828073.	8.29	0.004
FL	2		3373541.	1686771.	16.90	<.001
PD.Landrace	2		451860.	225930.	2.26	0.104
PD.FL	4		2545539.	636385.	6.37	<.001
Landrace.FL	2		15167.	7584.	0.08	0.927
PD.Landrace.FL	4		93881.	23470.	0.24	0.919
Residual	1330		132782203.	99836.		
Total	1347		153307751.			

Variate: CCI (umol m^{-2})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	4719.3	2359.7	12.64	<.001
Landrace	1	417.8	417.8	2.24	0.135
FL	2	64.2	32.1	0.17	0.842
PD.Landrace	2	75.9	37.9	0.20	0.816
PD.FL	4	143.0	35.7	0.19	0.943

Landrace.FL	2	221.5	110.8	0.59	0.553
PD.Landrace.FL	4	383.2	95.8	0.51	0.726
Residual	1332	248704.5	186.7		
Total	1349	254729.3			

Variate: PAR Above (mol m^{-2} s^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	3935504.	1967752.	12.89	<.001
Landrace	1	16003.	16003.	0.10	0.746
FL	2	407461.	203731.	1.34	0.264
PD.Landrace	2	59402.	29701.	0.19	0.823
PD.FL	4	31673.	7918.	0.05	0.995
Landrace.FL	2	52305.	26152.	0.17	0.843
PD.Landrace.FL	4	19164.	4791.	0.03	0.998
Residual	1332	203271918.	152607.		
Total	1349	207793432.			

Variate: PAR Below (mol m^{-2} s^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	5238793.	2619397.	22.06	<.001
Landrace	1	79918.	79918.	0.67	0.412
FL	2	540117.	270058.	2.27	0.103
PD.Landrace	2	71016.	35508.	0.30	0.742
PD.FL	4	106912.	26728.	0.23	0.924
Landrace.FL	2	49400.	24700.	0.21	0.812
PD.Landrace.FL	4	69699.	17425.	0.15	0.964
Residual	1332	158152881.	118733.		
Total	1349	164308735.			

Variate: SC (mmol $m^{-2}s^{-1}$)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

PD	2	3680.	1840.	1.13	0.323
Landrace	1	13180.	13180.	8.09	0.005
FL	2	18132.	9066.	5.57	0.004
PD.Landrace	2	1354.	677.	0.42	0.660
PD.FL	4	2397.	599.	0.37	0.832
Landrace.FL	2	542.	271.	0.17	0.847
PD.Landrace.FL	4	470.	118.	0.07	0.991
Residual	1332	2169331.	1629.		
Total	1349	2209086.			

Variate: SWC (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	7737.83	3868.92	203.58	<.001
Landrace	1	8.69	8.69	0.46	0.499
FL	2	2.10	1.05	0.06	0.946
PD.Landrace	2	15.66	7.83	0.41	0.662
PD.FL	4	11.34	2.83	0.15	0.963
Landrace.FL	2	4.62	2.31	0.12	0.886
PD.Landrace.FL	4	35.98	8.99	0.47	0.755
Residual	1332	25313.60	19.00		
Total	1349	33129.82			

Yield and yield parameters

Variate: Biomass plant^{-1} (kg)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	9.98372	4.99186	109.89	<.001
Landrace	1	0.91316	0.91316	20.10	<.001
FL	2	2.35127	1.17563	25.88	<.001
PD.Landrace	2	2.95769	1.47884	32.55	<.001
PD.FL	4	1.29935	0.32484	7.15	<.001
Landrace.FL	2	0.11649	0.05825	1.28	0.279

PD.Landrace.FL	4	0.39223	0.09806	2.16	0.074
Residual	252	11.44755	0.04543		
Total	269	29.46146			

Variate: Corm mass plant^{-1} (kg)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	4.62099	2.31049	75.94	<.001
Landrace	1	0.60029	0.60029	19.73	<.001
FL	2	1.15013	0.57506	18.90	<.001
PD.Landrace	2	1.60691	0.80346	26.41	<.001
PD.FL	4	0.74587	0.18647	6.13	<.001
Landrace.FL	2	0.05925	0.02962	0.97	0.379
PD.Landrace.FL	4	0.11589	0.02897	0.95	0.434
Residual	252	7.66707	0.03042		
Total	269	16.56640			

Variate: Corm number plant^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	5002.69	2501.34	206.80	<.001
Landrace	1	302.95	302.95	25.05	<.001
FL	2	296.07	148.03	12.24	<.001
PD.Landrace	2	435.74	217.87	18.01	<.001
PD.FL	4	206.78	51.69	4.27	0.002
Landrace.FL	2	52.45	26.23	2.17	0.117
PD.Landrace.FL	4	58.13	14.53	1.20	0.311
Residual	252	3048.00	12.10		
Total	269	9402.80			

Variate: Harvest Index (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	2155.42	1077.71	12.05	<.001

Landrace	1	321.61	321.61	3.60	0.059
FL	2	1047.91	523.95	5.86	0.003
PD.Landrace	2	1936.44	968.22	10.82	<.001
PD.FL	4	574.87	143.72	1.61	0.173
Landrace.FL	2	15.10	7.55	0.08	0.919
PD.Landrace.FL	4	1346.06	336.51	3.76	0.005
Residual	252	22543.36	89.46		
Total	269	29940.7			

Variate: Yield (kg. ha^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	2.282E+09	1.141E+09	75.94	<.001
Landrace	1	2.964E+08	2.964E+08	19.73	<.001
FL	2	5.680E+08	2.840E+08	18.90	<.001
PD.Landrace	2	7.935E+08	3.968E+08	26.41	<.001
PD.FL	4	3.683E+08	9.208E+07	6.13	<.001
Landrace.FL	2	2.926E+07	1.463E+07	0.97	0.379
PD.Landrace.FL	4	5.723E+07	1.431E+07	0.95	0.434
Residual	252	3.786E+09	1.502E+07		
Total	269	8.181E+09			

Nutritional content

Variate: Al (mg kg^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	829.803	414.902	239.08	<.001
Landrace	1	11.672	11.672	6.73	0.014
FL	2	1945.436	972.718	560.52	<.001
PD.Landrace	2	225.361	112.680	64.93	<.001
PD.FL	4	1484.853	371.213	213.91	<.001
Landrace.FL	2	919.814	459.907	265.02	<.001
PD.Landrace.FL	4	1604.658	401.164	231.17	<.001

Residual	36	62.474	1.735		
Total	53	7084.071			

Variate: B (mg kg^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	3.2762	1.6381	9.40	<.001
Landrace	1	0.2437	0.2437	1.40	0.245
FL	2	4.5798	2.2899	13.15	<.001
PD.Landrace	2	0.3617	0.1808	1.04	0.365
PD.FL	4	0.8673	0.2168	1.24	0.310
Landrace.FL	2	1.1429	0.5714	3.28	0.049
PD.Landrace.FL	4	2.2943	0.5736	3.29	0.021
Residual	36	6.2712	0.1742		
Total	53	19.0369			

Variate: Ca (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	0.0049452	0.0024726	12.29	<.001
Landrace	1	0.0004097	0.0004097	2.04	0.162
FL	2	0.0015136	0.0007568	3.76	0.033
PD.Landrace	2	0.0014433	0.0007216	3.59	0.038
PD.FL	4	0.0050712	0.0012678	6.30	<.001
Landrace.FL	2	0.0017958	0.0008979	4.46	0.019
PD.Landrace.FL	4	0.0028082	0.0007020	3.49	0.017
Residual	36	0.0072432	0.0002012		
Total	53	0.0252301			

Variate: Cu (mg kg^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	47.1790	23.5895	27.04	<.001
Landrace	1	0.0771	0.0771	0.09	0.768

FL	2	15.8159	7.9080	9.06	<.001
PD.Landrace	2	0.8079	0.4040	0.46	0.633
PD.FL	4	8.1980	2.0495	2.35	0.073
Landrace.FL	2	17.3430	8.6715	9.94	<.001
PD.Landrace.FL	4	6.2598	1.5649	1.79	0.151
Residual	36	31.4074	0.8724		
Total	53	127.0880			

Variate: Fe (mg kg^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	703.9	352.0	1.94	0.158
Landrace	1	125.1	125.1	0.69	0.412
FL	2	1552.5	776.2	4.28	0.021
PD.Landrace	2	870.3	435.2	2.40	0.105
PD.FL	4	580.1	145.0	0.80	0.533
Landrace.FL	2	931.5	465.8	2.57	0.090
PD.Landrace.FL	4	405.1	101.3	0.56	0.694
Residual	36	6522.7	181.2		
Total	53	11691.2			

Variate: K (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	0.57965	0.28982	16.78	<.001
Landrace	1	0.16958	0.16958	9.82	0.003
FL	2	1.05925	0.52963	30.66	<.001
PD.Landrace	2	0.09089	0.04544	2.63	0.086
PD.FL	4	0.56178	0.14044	8.13	<.001
Landrace.FL	2	0.35452	0.17726	10.26	<.001
PD.Landrace.FL	4	1.18318	0.29579	17.12	<.001
Residual	36	0.62191	0.01728		
Total	53	4.62075			

Variate: Mg (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	0.0066831	0.0033415	24.84	<.001
Landrace	1	0.0006080	0.0006080	4.52	0.040
FL	2	0.0015876	0.0007938	5.90	0.006
PD.Landrace	2	0.0000811	0.0000406	0.30	0.742
PD.FL	4	0.0055571	0.0013893	10.33	<.001
Landrace.FL	2	0.0010105	0.0005053	3.76	0.033
PD.Landrace.FL	4	0.0021926	0.0005481	4.07	0.008
Residual	36	0.0048432	0.0001345		
Total	53	0.0225633			

Variate: Mn (mg kg^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	1974.932	987.466	443.81	<.001
Landrace	1	201.278	201.278	90.46	<.001
FL	2	2208.034	1104.017	496.19	<.001
PD.Landrace	2	137.414	68.707	30.88	<.001
PD.FL	4	1717.448	429.362	192.97	<.001
Landrace.FL	2	641.778	320.889	144.22	<.001
PD.Landrace.FL	4	312.127	78.032	35.07	<.001
Residual	36	80.099	2.225		
Total	53	7273.110			

Variate: Na (mg kg^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	116890.722	58445.361	12138.80	<.001
Landrace	1	23242.575	23242.575	4827.36	<.001
FL	2	120723.254	60361.627	12536.80	<.001
PD.Landrace	2	92116.239	46058.119	9566.03	<.001
PD.FL	4	207766.587	51941.647	10788.01	<.001

Landrace.FL	2	65060.596	32530.298	6756.37	<.001
PD.Landrace.FL	4	105492.169	26373.042	5477.54	<.001
Residual	36	173.331	4.815		
Total	53	731465.473			

Variate: P (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	0.027114	0.013557	5.06	0.012
Landrace	1	0.000030	0.000030	0.01	0.916
FL	2	0.009524	0.004762	1.78	0.183
PD.Landrace	2	0.000089	0.000045	0.02	0.984
PD.FL	4	0.011295	0.002824	1.05	0.393
Landrace.FL	2	0.007088	0.003544	1.32	0.279
PD.Landrace.FL	4	0.004125	0.001031	0.39	0.818
Residual	36	0.096376	0.002677		
Total	53	0.155641			

Variate: Total C (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	0.4109	0.2054	0.39	0.682
Landrace	1	0.0462	0.0462	0.09	0.770
FL	2	1.2349	0.6175	1.16	0.324
PD.Landrace	2	0.0816	0.0408	0.08	0.926
PD.FL	4	0.5468	0.1367	0.26	0.903
Landrace.FL	2	0.1457	0.0729	0.14	0.872
PD.Landrace.FL	4	0.0447	0.0112	0.02	0.999
Residual	36	19.1295	0.5314		
Total	53	21.6403			

Variate: Total N (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

PD	2	0.18818	0.09409	2.54	0.093
Landrace	1	0.00008	0.00008	0.00	0.964
FL	2	0.11891	0.05946	1.61	0.215
PD.Landrace	2	0.03826	0.01913	0.52	0.601
PD.FL	4	0.05736	0.01434	0.39	0.816
Landrace.FL	2	0.03424	0.01712	0.46	0.633
PD.Landrace.FL	4	0.08664	0.02166	0.58	0.676
Residual	36	1.33293	0.03703		
Total	53	1.85659			

Variate: Total S (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	0.0013991	0.0006996	4.94	0.013
Landrace	1	0.0000282	0.0000282	0.20	0.658
FL	2	0.0009729	0.0004865	3.44	0.043
PD.Landrace	2	0.0003370	0.0001685	1.19	0.316
PD.FL	4	0.0009763	0.0002441	1.72	0.166
Landrace.FL	2	0.0003001	0.0001501	1.06	0.357
PD.Landrace.FL	4	0.0029256	0.0007314	5.17	0.002
Residual	36	0.0050953	0.0001415		
Total	53	0.0120345			

Variate: Zn (mg kg^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	9639.750	4819.875	1418.68	<.001
Landrace	1	1912.565	1912.565	562.94	<.001
FL	2	593.946	296.973	87.41	<.001
PD.Landrace	2	5084.967	2542.484	748.35	<.001
PD.FL	4	13390.553	3347.638	985.34	<.001
Landrace.FL	2	3432.202	1716.101	505.12	<.001
PD.Landrace.FL	4	8007.939	2001.985	589.26	<.001
Residual	36	122.308	3.397		

Total	53	42184.229			

Variate: Total C (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	0.4109	0.2054	0.39	0.682
Landrace	1	0.0462	0.0462	0.09	0.770
FL	2	1.2349	0.6175	1.16	0.324
PD.Landrace	2	0.0816	0.0408	0.08	0.926
PD.FL	4	0.5468	0.1367	0.26	0.903
Landrace.FL	2	0.1457	0.0729	0.14	0.872
PD.Landrace.FL	4	0.0447	0.0112	0.02	0.999
Residual	36	19.1295	0.5314		
Total	53	21.6403			

Feed moisture and starch content

Variate: Feed Moisture (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	12.401	6.201	4.10	0.025
Landrace	1	1.039	1.039	0.69	0.412
FL	2	45.058	22.529	14.91	<.001
PD.Landrace	2	196.277	98.139	64.95	<.001
PD.FL	4	109.858	27.464	18.18	<.001
Landrace.FL	2	13.542	6.771	4.48	0.018
PD.Landrace.FL	4	174.055	43.514	28.80	<.001
Residual	36	54.392	1.511		
Total	53	606.622			

Variate: Feed Starch (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PD	2	3792.405	1896.202	1126.18	<.001

Landrace	1	236.003	236.003	140.16	<.001
FL	2	615.290	307.645	182.71	<.001
PD.Landrace	2	957.932	478.966	284.46	<.001
PD.FL	4	1233.795	308.449	183.19	<.001
Landrace.FL	2	62.859	31.430	18.67	<.001
PD.Landrace.FL	4	898.128	224.532	133.35	<.001
Residual	36	60.615	1.684		
Total	53	7857.027			