Planting density effect on growth and yield of taro (*Colocasia esculenta*) landraces

by

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PREFACE

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

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

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Signed: Professor Albert T. Modi

Date: 15 December, 2015

DECLARATION

I, Sindisiwe Gugu Sibiya, declare that:

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

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

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

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

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

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

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

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

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ABSTRACT

Taro (*Colocasia esculenta*), or amadumbe (in isiZulu), currently occupies low levels of utilisation in South Africa. Information describing its agronomy is still scant. The aim of this study was to determine the effect of planting density on growth and yield of taro landraces. A secondary objective was to determine the effect of water stress on growth and yield of taro landraces. Three taro landraces, two eddo types [Dumbe dumbe (DD) and Dumbe omhlophe (DO)] and one dasheen type [Dumbe pondo (DP)] were collected from rural areas across KwaZulu-Natal. A field trial was conducted at two sites, Umbumbulu and Ukulinga Research Station. A controlled environment experiment was also conducted at the University of KwaZulu-Natal's Controlled Environment Facility. For the field trials, the experimental design was a split-plot design arranged in randomised complete blocks replicated three times. The main factor was planting density [low (1 m x 1 m), medium (1 m x 0.5 m) and high (0.5 m x 0.5 m)] with the varieties allocated to the sub- plots. For the Controlled Environment Facility study, the experimental design was also a split-plot, with water [30% and 100% of crop water requirement (ETa)] as the main factor and two landraces as the sub-plots, replicated three times. Results of the field trial showed that emergence was affected by plant density, with plants emerging slower at high planting density. Growth and yield responded positively to increasing plant density with yield being highest at high plant density. Result for controlled environment study showed that emergence was slower at 30% ETa relative to 100% ETa. Growth was negatively affected by water stress. This translated into yield whereby yield was lower at 30% relative to 100% ETa. In terms of taro landraces, the DD landrace generally performed better than both DO and DP landraces. It was concluded that planting the DD landrace at a high plant density was recommended for upland cultivation of taro. Future studies should evaluate the yield quality of taro landraces.

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DEDICATION

This thesis is dedicated to the memory of my beloved late daughter, **Khetheka Sinokuhle Zuma** who regretfully did not live to see this work.

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LIST OF ABBREVIATIONS

CCI – Chlorophyll content index

CEF- Controlled Environment Facility

CBDC- Colocasia Bone Disease Virus

DAFF- Department of Agriculture Forest and Fisheries

DD - Dumbe Dumbe

DO – Dumbe Omhlophe

DP – Dumbe Pondo

DsMV- Dasheen Mosaic Virus

ETa- Evapotranspiration

FAO – Food and Agriculture Organisation

KZN – KwaZulu-Natal

M.a.sl- Meters above sea level

NAIR – National Agricultural Research Institute

RH- Relative Humidity

SA- South Africa

SASRI- South African Sugarcane Research Institute

SWC – Soil Water Content

UKZN – University of KwaZulu-Natal

TaBV- Taro Bacilliform Virus

WAP – Weeks after Planting

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CHAPTER 1

INTRODUCTION

1.1 Introduction and Rationale

Taro [*Colocasia esculenta* (L) Schott] commonly known as amadumbe in isiZulu (DAFF, 2010; Mare and Modi, 2012) is one of the important members of the edible aroids that belong to the monocotyledonous family Araceae and is widely planted in tropical and sub-tropical areas (Onwueme, 1978; Modi, 2007; Talwana et al., 2010; Mabhaudhi et al., 2014). It is propagated vegetatively, generally from suckers, but can also flower and set seed (Wang, 1983; Chand et al., 1998; Kreike et al., 2004). Taro, the potato of the tropics, is an important crop in many parts of Africa and Latin America (Plucknett, 1984; Pardales, 1986; DAFF, 2010). It is a staple food for millions of people and it is commonly grown by small scale farmers who operate within the subsistence economy (Pardales, 1986).

It is grown in all tropical and sub–tropical regions of the world and can tolerate high rainfall provided there is good drainage. Taro is one of the few major staple foods where both the leaf and underground parts are important in the human diet (Deo et al., 2009).The corm and cormels, which are the major economic parts, have a nutritional value comparable to potato (Wang, 1983), while the young leaves and petioles, which are occasionally used for food contain about 23% protein on a dry weight basis. It is also a rich source of calcium, phosphorus, iron, Vitamin C, thiamine, riboflavin and niacin, which are important constituents of human diets (Onwueme, 1999; Paul and Bari, 2011). Taro is a good source of carbohydrate, contains adequate protein and has low lipid content. Its protein content is higher than that of sweet potatoes and cassava (Deo et al., 2009).

According to Mabhaudhi and Modi (2013), taro originated from tropical America and Asia. Various lines of ethno-botanical evidence suggest that taro originated in South Central Asia, probably in India or the Malay (Spier, 1951; Shange, 2004; Modi, 2004), and then spread to the Pacific Islands (Wang, 1983).

Taro is used as food and prepared the same way as potatoes. Its flour is considered good baby food because its starch is easily digestible; and it helps with digestive problems and supplements iron (Onwueme, 1999; Shange, 2004). Taro's primary use is the consumption of its edible corm and leaves, since they are a good source of carotene, potassium, calcium, phosphorus, and iron (Deo et al., 2009). Mature corms and young shoots are mostly used as boiled vegetable and corms can also be baked, roasted, and fried. Boiled corms are mashed and used as a weaning diet. Taro production in South Africa predominantly occurs in KwaZulu-Natal, Mpumalanga and Eastern Cape producing regions. Common names for taro differ according to region and language spoken (DAFF, 2011).

1.2 Justification

The fact that taro has potential to contribute to food security and its ability to thrive under conditions that are adverse for most crops e.g. water logged conditions makes it an ideal subsistence crop for areas where advanced agricultural technology is lacking. It can survive both waterlogged and upland conditions. It is one of the neglected and underutilised crops about which more agronomic knowledge is required regarding its production in South Africa. Planting density is an important aspect of crop management**.**

1.3 Aims and objectives

The aim of the study was to evaluate the effect of planting density and moisture on yield and development of three taro landraces.

1.3.1 Specific objectives

- To determine the effect of planting density on growth and yield of three taro landraces.
- To determine the effect of different water levels on growth, development, and yield of three taro landraces under controlled environment conditions.

CHAPTER 2

LITERATURE REVIEW

2.1 Botany and Ecology

2.1.1 Classification of taro

Taro [*Colocasia esculenta* (L) Schott] is a major root crop of the monocotyledonous family *Araceae* (Singh et al., 2007; Modi, 2007; Mare, 2009), sub-family *Aroideae*, whose members are referred to as aroids (Lebot, 2009). The family contains about 110 genera and 200 species, which are mainly distributed in the tropical and subtropical regions of the world (Shange, 2004; Modi, 2004; Modi, 2007). Cultivated taro is classified as *Colocasia esculenta*, but the species is considered to be polymorphic (Purseglove, 1972; Onwueme, 1994). There are two botanical varieties distinguished by their corms, cormels, shoot characteristics, or on the basis of agronomic behaviour (Purseglove, 1972; Joubert and Allemann, 1998; Paul and Bari, 2011); var. *esculenta* (dasheen type), and va*r. antiquorum* (eddoe type) (Kreike et al., 2004; Tumuhimbise et al., 2009). There are many varieties of taro, but there are mainly two varieties that exist in South Africa, the eddoe and dasheen types. They are differentiated by their growth habit, corm shape, corm flesh colour, crop cycle and culture (Joubert and Allemann, 1998).

The Dasheen type (Figure 2.1 A) produces one large cylindrical main corm with few cylindrical side corms, which run some distance from the main plant before developing into suckers. Growth cycle is 8 -10 months (Joubert and Allemann, 1998; Singh et al., 2007; Robin, 2008).The Eddoe type (Figure 2.1 B) produces relatively small corm, round to oval shape, with mainly smaller corms compactly arranged around the base of the main corm (Joubert, 1997) .

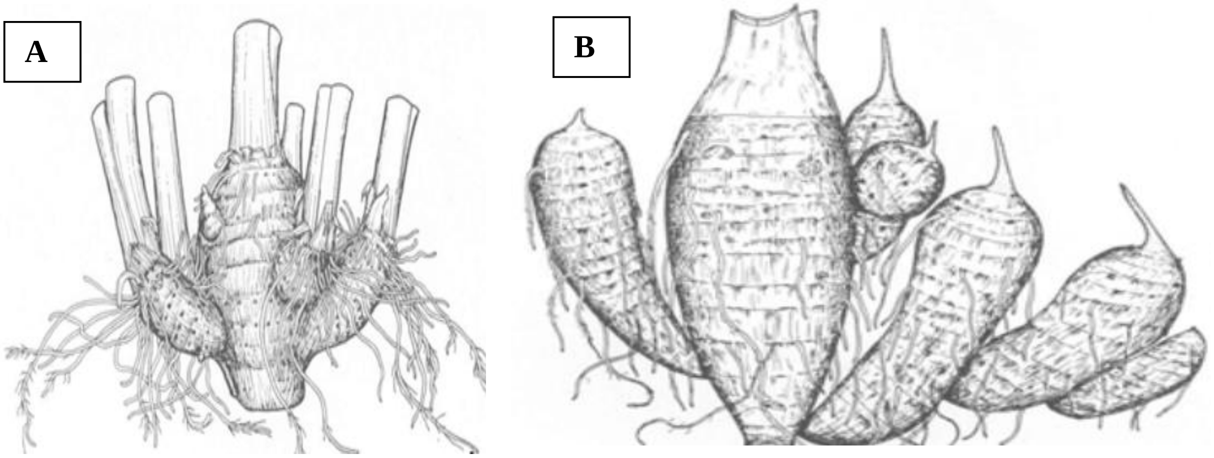

Figure 2.1: A- Diagrammatic representations of dasheen type of taro with the main corm (var. *esculenta*) and B- an eddoe type with cormels (var. *antiquorum*).

Corm flesh colour varies from cream to white. Leaf stem colour: red violet tip near leaf blade attachment (Modi, 2007), graded into dark green with a red violet mottling, pinkish with a basal ring where the stem meets the corm. Crop growth cycle is 6 to 8 months, depending on the climate of the area (Joubert, 1995; Joubert and Allemann, 1998).

2.1.2 Origin and distribution

Taro originated from tropical America (Wang, 1983; Lebot, 2009), from its centre of origin, taro spread eastward to the rest of South East Asia, and to China, Japan and the Pacific Islands. Some authors have suggested that the island of New Guinea may have been another centre of origin for taro, quite distinct from the Asian centre. From Asia, taro spread westward to Arabia and the Mediterranean region. By 100 B.C., it has been grown in China and in Egypt (Van Wyk, 2000). It arrived on the east coast of Africa over 2,000 years ago; it was taken by voyagers, first across the continent to West Africa, and later on slave ships to the Caribbean. Today, taro is pan-tropical in its distribution and cultivation. The greatest intensity of its cultivation, and its highest percentage contribution to the diet, occurs in the Pacific Islands. However, the largest area of cultivation is in West Africa, which accounts for the greatest quantity of production. Significant quantities of taro are also grown in the Caribbean, and virtually all humid or sub-humid parts of Asia. It has been suggested that the eddoe type of taro was developed and selected from cultivated taro in China and

Japan several centuries ago, and it was later introduced to the West Indies and other parts of the world (Purseglove, 1972).

2.1.3 Morphology and anatomy

Taro is an herbaceous plant, which grows up to a height of 1-2 meters (Miyasaka et al., 2003; Deo et al*.,* 2009). The main plants consist of suckers, which can grow from 40 -100 cm (FAO, 1998). It has the central corm from which leaves grow upwards, roots grow downwards, while cormels, daughter corms and runners (stolons) grow laterally (Figure 2.2). The root system is fibrous and lies mainly in the top one meter of soil (Joubert and Allemann, 1998), green heart shaped leaves 20-50 cm long are found on leaf steams of 30-90 cm in length. It is propagated vegetatively generally from suckers, but can also flower and set seed (Wang, 1983; Chand et al., 1998; Kreike et al*.,* 2004).

Flowers and fruits are rarely produced (Wang, 1983; Deo et al., 2009); flowers are tiny, densely crowded on the upper part of the fleshy stalk, with female flowers below and male flowers above, fruits in small berry, in clusters on the fleshy stalk (Onwueme, 1999).

Taro possesses enlarged, starchy, underground stems which are properly designated corms (Deo et al., 2009). These have been found to be highly variable with respect to hydration, size, colour, and chemistry. The corm is composed, outwardly, of concentric rings of leaf scars and scales. It bears one or more smaller secondary cormels which arise from lateral buds present under each scale or leaf base (Onwueme, 1978). Shape varies from elongated to spherical with an average diameter of 15 to 18 cm. anatomically, the tuber is composed of a thick, brown outer covering within which lies the starch-filled ground parenchyma (Wang, 1983).

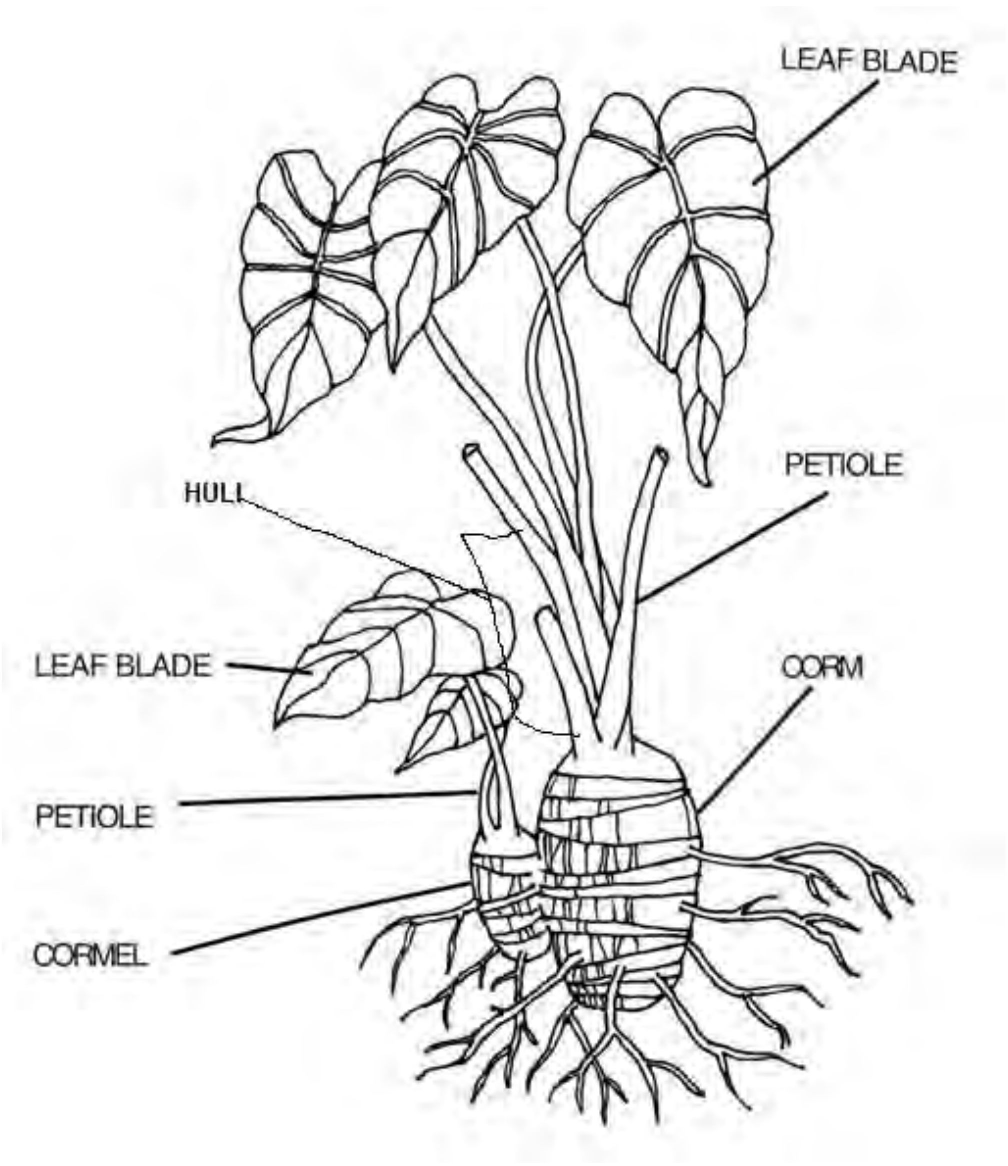

Figure 2.2: Taro plant showing leaves, corms, cormels and suckers (Miyasaka et al., 2003).

In the dasheen types of taro, the corm is cylindrical and large up to 30 cm long and 15 cm in diameter, and constitutes of the main edible part of the plant. In eddoe types, the corm is small, globoid, and surrounded by several cormels and daughter corms. The cormels and the daughter corms together constitute a significant proportion of the edible harvest in eddoe taro. Daughter corms usually remain dormant and will only give rise to new shoots if left in the ground after the death of the main plant (Onwueme, 1978).

The root system of taro is adventitious and fibrous. It is generally restricted to the upper levels of the soil, though arising from the lower portions of the corm (Onwueme, 1978; FAO, 1998). Occasionally in the field, some taro plants are observed to produce suckers. These structures grow horizontally along the surface of the soil for some distance, rooting down at intervals to give rise to new erect plants.

The surface of each corm is marked with rings showing the points of attachment of scale leaves in both eddoe and dasheen type. The actively growing leaves arise in a whorl from the corm apex. These leaves effectively constitute the only part of the plant that is visible above ground. They determine the plant's height in the field; each leaf is made up of an erect petiole and a large lamina. The petiole is 0.5 to 2 m long and is flared out at its base where it attaches to the corm, so that it effectively clasps around the apex of the corm. The petiole is thick at the base, and thinner towards the lamina (FAO, 1999).

2.1.4 Growth cycle and development stages

Growth, maturity and harvest period of taro depend upon cultivar. After planting, growth rate is slow but increases rapidly after 1 to 2 months (Onwueme, 1999). Corm quality, which is the size and shape, is determined at different growth stages in taro. There are four growth stages (Figure 2.3) in taro, namely: establishment, vegetative growth, and corm initiation and bulking through maturation (Mare, 2009).

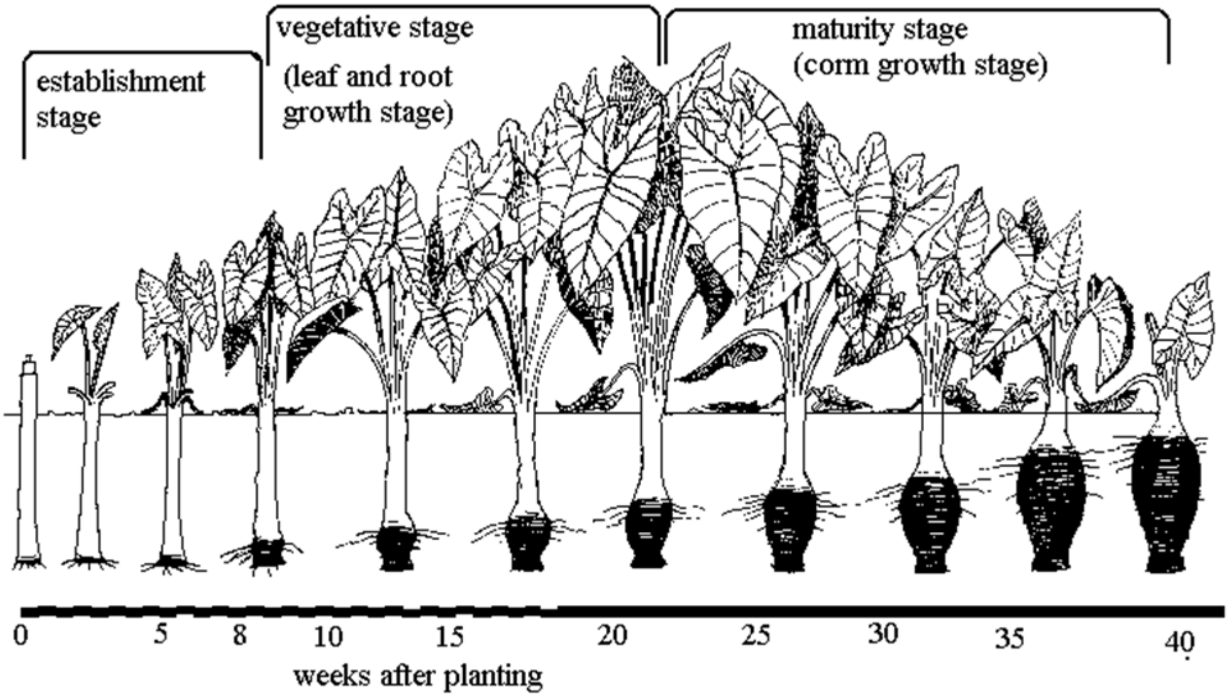

Figure 2.3: Diagrammatic representation consist of different growth stages in Taro (Singh, 1992).

The period of establishment comprises root formation and leaf production (Sivan, 1982). This stage is characterized by sprouting and root growth. Successful establishment is a critical requirement for efficient crop production and is primarily determined by propagule size (Mare, 2009). In taro, propagule size is crucial for successful establishment because at this stage plants are entirely supported by available carbohydrates from the seed piece up to a plant leaf area of 400 cm^2 $plant^{-1}$ (Singh et al., 1998).

The period of rapid root and shoot development overlaps with initiation and development of corms during five months after planting (Sivan, 1982). Vegetative growth is marked by an increase in plant height, number of leaves and leaf area and slow corm growth (Tumuhimbise et al., 2007; Silva et al. 2008). The leaf and stem are the dominant sinks for assimilates at this stage (Singh et al., 1998).

Taro maturity stage is the period where roots and shoot growth is at peak, with a rapid increase in corm formation. There is a leaf senescence period associated with decreasing root and shoot growth with continued increase in corm size as the crop matures (Sivan, 1982). The leaf development decreases in intensity and the plant growth is reduced (Silva et al., 2008). At this stage there is rapid decline in shoot growth and total shoot dry weight, and reduction in the number of active leaves, decrease in the mean petiole length, a decrease in the total leaf area per plant, and a decrease in the mean plant height (Onwueme, 1999). According to Goenega (1995), corm bulking occurred after the attainment of maximum leaf area indices and the partitioning of dry matter to the corms remained constant from 150 days after planting. Tumuhimbise et al. (2007) also reported that maturity is a period of growth in which corm diameter and length increased rapidly throughout the 150 days.

2.1.5 Uses

According to Budi and Jenishinn (2009), taro is used as food and prepared the same way as potatoes. Taro's primary use is the consumption of its edible corms and leaves, since they are a good source of carotene, potassium, calcium, phosphorus, and iron (Deo et al., 2009). Mature corms and young shoots are mostly used as boiled vegetable and corms can also be baked, roasted, and fried (Lewu et al., 2009). Boiled corms are mashed and used as a weaning diet. Its flour is considered good for infant formula and canned baby foods because its starch is easily digestible; and it helps with digestive problems and supplements iron (Joubert and Allemann, 1998; Onwueme, 1999; Shange, 2004). The edible corms have higher starch content than either potatoes or sweet potatoes, its flour is considered good for baby food and it is recommended for gastric patients (Tumuhimbise et al., 2009). Eddoes offer an intensely flavourful alternative to potatoes and yams. Eddoe contains carbohydrates and fibres which are excellent for people with digestive problems (FOA, 1992; FAO, 1998). Cormels arising from the main corm are the main harvestable yield. However, eddoe is more drought tolerant than dasheen and cormels have longer storage life. Other benefits include lowering cholesterol levels, slowing absorption of glucose, reducing insulin requirement and reducing the likelihood of colorectal cancer (Wilbert, 1986).

Taro has a number of medicinal uses (Paul and Bari, 2011); corms are used as an abortifacient, and to treat tuberculous ulcers, pulmonary congestion, crippled extremities, fungal abscesses in animals, and as an anthelmintic. Foliage is used as a styptic and poultice. The stem sap is used as a treatment for wasp stings (Wilbert, 1986). It is also a good source of dietary fibre compared to other root and tuber crops. However, high levels of dietary fibre in foods are also advantageous for their active role in the regulation of intestinal transit, increasing dietary bulk and improving faeces consistency due to their ability to absorb water (Wilbert, 1986).

2.2. Environmental Requirements

2.2.1 Climate

Taro is grown in different climatic conditions (Smith, 2006). It is adapted to moist environment but can be grown under rainfed or irrigated upland as well as flooded conditions (Plucknett *et al*., 1970; Miyasaka et al., 2003). Taro crops reportedly yield well if the annual average rainfall is at least 1500 mm and is evenly distributed throughout the growing season. For example, much of the upland taro grown in Hawaii is not irrigated, as crops depend on the regular rainfall. Optimum yields are obtained in areas with rainfall exceeding 2500 mm (Onwueme, 1999). The Eddoe variety is more adapted to lower temperatures, humidity levels and lower rainfall conditions than the Dasheen (Onwueme, 1999). Production areas for the Dasheen are mainly restricted to the coastal belt of the North Eastern regions of KwaZulu-Natal (Joubert and Allemann, 1998; Shange, 2004).

2.2.2 Temperature and humidity

The optimum temperature range for growth is between 21ºC and 27ºC; the crop prefers warm conditions because they cannot withstand freezing. High humidity is preferred, with well distributed summer rainfall of 1000mm and more or supplemental irrigation. Low moisture and high temperature can limit productivity due to detrimental effect on taro growth (Pardales, 1985; Pardales, 1986). The eddoe variety is more adapted to lower temperatures, humidity levels and lower rainfall conditions than the Dasheen. Production areas for Dasheen are mainly confined to the coastal belt of the Northern Eastern Regions of KwaZulu - Natal (Joubert and Allemann, 1998; Smith, 2006).

2.2.3 Photoperiod and light intensity

Photoperiod is the interval in 24 hour period during which the plant is exposed to light (Allemann and Hammes, 2006). Development and growth response of taro to an increase in temperature and photoperiod has not been studied much, and little is known of photoperiod effects on leaf number and corm yield (Prasad and Singh, 1992) (Table 2.1). In most species storage organ formation is promoted by short periods, whereas in crops like onions it is promoted by long days (Allemann and Hammes, 2006). The formation of corms and cormels is promoted by short-day conditions, while flowering is promoted by long-day conditions (Onwueme, 1999). Aroids are shade tolerant crops. Taro plants grown at 30% of full sunlight have increased stomatal and chlorophyll density which increases photosynthetic efficiency at low levels of light (Lebot 2009). According to Prasad and Singh (1992), taro grown under artificial shade of 50% canopy were reported to have high plant height and leaf area compared to full sunlight, total plant biomass is also increased by shade; corm yields are not affected by the shade but the number and weight of plant suckers are increased (Lebot, 2009). The highest yields for taro are obtained under full light intensity; this also means that good yields can be obtained even in shade conditions where other crops might fail completely. This is the other important characteristic which enables taro to fit into unique intercropping systems with tree crops and other crops (Lebot, 2009).

Table 2.1: The main effect of photoperiod on cormel number and yield of taro (Prasad and Singh, 1992, Lebot, 2009).

Photoperiod	**Cormel number**	**Dry Weight (*g plant*$^{-1}$)**		
		Corm	**Cormel**	**Total Biomass**
PO	16.9	397.3	500.4	989.8
P1	18.7	367.9	541.9	1023.6
P2	21.0	406.4	568.0	1073.3
P3	20.4	428.3	583.7	1098.7
P4	22.3	361.8	572.5	1002.2

2.2.4 Water

Taro is one of the least water efficient crops, and can tolerate high rainfall areas with good drainage (Uyeda et al., 2011). The amount of water available with its distribution pattern has an important effect on the cycle time of the crop. High amounts of water or irrigation result in increased yields and longer growing period, if the favourable growing conditions are experienced. Taro can be cultivated under both dry land and irrigated land, some varieties do well in both conditions. Optimum rainfall is 1400 mm - 2000 mm (DAFF, 2011). It is important to ensure a constant availability of water throughout the growing season, as shortages of water may cause water stress, which results in production of malformed corms which are of poor quality. Irrigation facilities must be provided where there is an irregular rainfall (Joubert and Allemann, 1998).

2.2.5 Soils

Taro can grow on a wide range of soil types from heavy clay loams, sandy loam to light volcanic soils (Onwueme, 1999). However, taro will yield well when planted in fertile soil that has a high water holding capacity and is rich in organic matter, can withstand occasional flooding without damage. A slightly acid soil in the range of pH 5.5 to 6.5 with moderate clay content is ideal. Permanently moist soils appear to be most desirable to maximize growth and yield. Moisture stress can be detrimental to growth and supplementary irrigation may have to be applied during dry periods. Soils with good drainage are preferred by all eddoes type. Dasheen grows best where soils are heavy and has high moisture holding capacity, and also under water logged soils conditions. Dasheen is slightly salt tolerant and has a great potential for cultivation in low lying areas subjected to flooding and salinity problems (Smith, 2006).

2.3 Taro Cultivation

In South Africa, taro is a traditional crop (Mabhaudhi and Modi, 2013) mostly produced in KwaZulu-Natal, Mpumalanga and Eastern Cape, with different common names like taro, amadumbe, mufhongwe, cocoyam, and amadumbe (DAFF, 2011). The crop is a traditional vegetable grown for subsistence use in KwaZulu-Natal province where a number of landraces (Modi, 2003) or farmer varieties already exist (Shange, 2004). It is mainly grown in this area because of the crop’s unique climatic requirements of warm environment, high annual rainfall and long wet season. KwaZulu-Natal primarily grows eddoe type landraces (Shange, 2004; Mare, 2009). In South Africa the production levels of taro are not well known since it is a traditional crop, and it is mostly produced by rural communities for subsistence use (DAFF, 2010, 2011). Commercialization has occurred in Umbumbulu, the rural district of KwaZulu-Natal. Commercialization of this crop is limited because of lack of improved cultivars (Mabhaudhi and Modi 2013).

2.3.1 Taro Planting

Taro may be planted in rows, ridges, furrows or in plots (Onwueme, 1999). Planting holes should be larger than the size of the corm, usually 10-20 cm depending on the size of the sett. Shallow planting will result in corms developing above the ground surface and these exposed corms are more likely to be damaged by insect pests and rodents. Crops should be watered soon after planting to remove air pockets. There are essentially four types of planting material that are used in taro production (Joubert and Allemann, 1998):

i) Side suckers produced as a result of lateral proliferation of the main plant in the previous crop,
ii) Small corms resulting from the main plant in the previous crop,
iii) Huli the apical 1-2 cm of the corm with the basal 15-20 cm of the petioles attached, and
iv) Corm pieces resulting when large corms are cut into smaller pieces.

Under dry land cultivation, planting is generally done at or shortly before the beginning of the wet season (Table 2.2). An early spring planting has a longer crop cycle and produces higher yields under favourable growing conditions than later (Joubert and Allemann, 1998).

Table 2.2: Common times of planting taro in different environmental conditions in South Africa (SA) (Shange, 2004).

Climate	Ideal times	Possible times
Warm	September – October	July – October
Hot	July – October	March – November

2.3.2 Planting density

Plant spacing used in taro affects taro growth, corm shape and taro yield due to competition for soil moisture, nutrients and light (Ezumah and Plucknett, 1981). Wider spacing tends to produce bigger, uniform corm shape and more suckers, whereas close spacing produces small corms (Joubert and Allemann, 1998). According to Tumuhimbise et al. (2009), plant population has been reported to impact taro growth, high plant population being associated with higher leaf area index corm yield due to high number of shoots per unit area. The average density is 10 000 plant /ha and depth of a sett depends on its size. It is safer to plant too deep than too shallow in order to alleviate the drying out of shoots (Lebot, 2009). The overall yield of taro may be improved by increasing the number of plants per unit area. When density is too high e.g. (0.3 m X 0.3 m), leaves die earlier, plants will then have fewer leaves and are thus prone to leaf diseases. In crops like cereals and other grain crops, an increase in planting density increases the total yield regardless of strong indications that individual plant productivity is reduced (Pardales and Belmonte, 1984). Other researchers believe that as population increases, there is a greater competition for water, nutrients and other growth factors, and the immediate effect is seen in foliage development which is a major determinant of yield (Weber et al., 1966; Pardales and Belmonte, 1984). Several studies (Weber et al. 1966; Pardales et al. 1982; Pardales and Belmonte 1984; Pardales 1986) previously done on taro showed that the main corm yield increases with increase in population but the individual corms become smaller as planting stand become denser. In areas, where growing conditions are not optimal, slightly wider spacing reduces the spread of disease. When planting taro close together, early canopy closure can be gained for more efficient capture of solar energy (Sivan, 1984; Joubert, 1995).

2.3.2 Diseases and pests

In many countries taro is being replaced by sweet potatoes and cassava due to pests and disease problems, which are becoming a limiting factor for taro production (Deo et al., 2009). Viruses are one of the most important pathogens with some infections resulting in severe yield reductions and plant death. The main effect of virus infection is a reduction in corm size and quality, with yield losses of up to 20% being reported. There are currently five viruses reported to infect taro. Dasheen mosaic virus (DsMV) is a potyvirus with flexuous, rod shaped structures, which infect both the edible and ornamental aroids are spread by aphids. It is characterized by chlorotic, feathery mosaic patterns on the leaf, distortion of leaves and stunted plant growth. There is some evidence that it decreases the yield (Deo et al. 2009). Taro bacilliform virus (TaBV), its infection with TaBV alone is thought to result in a range of mild symptoms including stunting, mosaic and down curling of the leaf blades. However, coinfection of taro with TaBV and CBDV is thought to result in the lethal alomae disease. *Colocasia* bone disease virus (CBDV) is a cytorhabdovirus**.** Alone, CBDV causes bobone disease. A complex of at least two viruses, CBDV and TaBV cause alomae disease. Symptoms first start as a feathery mosaic on the leaves; the lamina and veins become thick, the young leaves are crinkled and do not unfurl normally, while the petiole is short and manifests irregular outgrowth (Deo et al., 2009)

2.3.3 Economic importance

Taro is mostly produced and consumed on a subsistence basis, and surpluses are sold as cash crops, which plays a huge role in combating poverty (Onwueme, 1999).Taro corms have been reported to have a high economic value in urban markets in Uganda, and its production provides employment to many people while the crop maintains ground cover in the fields. However, there is very limited local research on Taro in Uganda and its actual contribution to food security and economy is underestimated (Tumuhimbise et al., 2009). Taro has attained considerable economic importance as a fresh crop in many large islands in the region such as Fiji and others (Deo et al., 2009). It has now become one of the major export commodities providing substantial foreign exchange to some of the Pacific Island countries.

2.3.5 Yield and yield components

Yield traits include total weight of cormels plant^{-1}, number of cormels plant^{-1} and mass of individual corms (Mare, 2009). Taro is a staple root crop for many countries in the Pacific and in Africa (Goenaga and Chardon, 1995) (Table 2.3). Current yields level of taro production are relatively low. Yield fluctuates because of difference in cultivar, planting density, fertilizer application levels, natural factors and cultivar (Manner and Taylor, 2010). Worldwide, the crop yields about 6000kg/ha compared to 15000 kg/ha of potato and 14000 kg/ha of sweet potatoes. In most countries, taro is grown under rainfed conditions which can lead to radical yield declines because of transient drought periods. Furthermore, yield potential of taro is seldom realized due to lack knowledge of diseases, poor management practices, and physiological determinants that may limit growth and development (Goenaga and Chardon, 1995).

Table 2. 3: Production, Yield and Area for Taro/Tannia in 1998 (FAO, 1999).

	Production (1000 tonnes)	**Yield (tonnes/ha)**	**Area (1,000 ha)**
World	6586	6.2	1070
Africa	4452	5.1	876
Asia	1819	12.6	144
China	1387	16.8	82
Japan	255	11.6	22
Philippines	118	3.4	35
Thailand	54	11.0	5
Oceania	283	6.2	46
Papua New Guinea	160	5.2	31
W. Samoa	37	6.2	6
Solomon Islands	28	21.9	1
Tonga	27	6.4	4
Fiji	21	14.7	1

2.4 Conclusion

Taro is an important edible aroid crop that is cultivated in South Africa mainly by smallholder farmers. This production is mainly confined to the coastal areas of KwaZulu-Natal, the Eastern Cape with limited inland and upland production in Mpumalanga. Despite taro being an important subsistence crop which has also been commercialised, there is still a gap with regards to knowledge on its production. Previous studies have made some headway in this regard, but more still needs to be done in order to better advise farmers and improve current yields. Plant density is an important agronomic decision for which there have been limited local studies evaluating optimum plant densities for local taro landraces.

CHAPTER 3

MATERIALS AND METHODS

3.1 Field Experiment

3.1.1 Plant materials

Three landraces were used in this study, namely: Dumbe pondo, Dumbe dumbe and Dumbe omhlophe in both locations. Dumbe pondo (DP) landrace was classified as dasheen type characterised by a large central corm which is edible and few side cormels (Joubert and Allemann, 1998), and it is propagated using sprouted corm and head setts. Growth cycle is 8–10 months (Singh et al., 2007). Dumbe dumbe (DD) and Dumbe omhlophe (DO) are eddoe types characterised by a central corm and side cormels which are the edible part (Lebot, 2009), with a red petiole at the upper 3–5 cm including the petiole-leaf blade interface (Modi, 2007), eddoes generally requires a minimum of six months to mature, however under rainfed conditions, they may be extended to 8-9 months, depending on growing conditions and cultivar type (NARI) (http://www.newgmc.com/gmc_docs). The three taro landraces (Figure 3.1) were sourced from two locations in KwaZulu-Natal (KZN). Dumbe pondo was sourced from smallholder farmers at Obanjeni (28°55' S, 31°42' E). Dumbe dumbe and Dumbe omhlophe were sourced from smallholder farmers at Umbumbulu (29°59' S, 30°42' E).

Figure 3.1: Dumbe pondo (A), Dumbe-dumbe (B), and Dumbe omhlophe (C) taro landraces.

3.1.2 Site descriptions

Field trials were carried out at two locations; Ukulinga Research Farm (29°37' S; 30°16' E; 805 m a.s.l) in Pietermaritzburg, and Umbumbulu (29°59'S, 30°42'E, 548 m a.s.l). The trial at Ukulinga was planted on the 6th of December 2013, and Umbumbulu on the 9th of December 2013 under rainfed conditions. Ukulinga farm has a subtropical climate with 694 mm annual precipitation received mainly during the summer season (October–March). The farm represents a semi-arid environment characterized by clay loamy soil. Umbumbulu area also has a sub–tropical climate with 956 mm mean annual rainfall and has sandy loam soils (http://sasri.sasa.org.za/irricane/tables

3.1.3 Experimental layout and design

For both sites, the experimental design was a split–plot laid out in randomised complete blocks replicated three times. The main plot was allocated to planting density. There were three planting densities [0.5 m x 0.5 m (40 000 plants ha^{-1}), 1 m x 0.5 m (20 000 plants ha^{-1}), and 1 m x 1 m (10 000 plants ha^{-1})], representative of high, medium and low plant densities, respectively. The taro landraces (DP, DD, and DO) were allocated to the sub–plots. Individual sub–plots were 12 m^2 (4 m x 3 m).

3.1.4 Data collection

Data collected included emergence, leaf number, plant height, chlorophyll content index (CCI), yield and yield components. Crop growth and development data were collected every fortnight. Emergence was defined as the protrusion of the shoot through the seed corm, 2 mm above the soil surface. Emergence was recorded when at least 90% of seedlings had 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. Chlorophyll content index was measured on the adaxial surface of the second youngest fully formed, fully unfolded leaf using a SPAD 502 chlorophyll content metre (Minolta, USA). Yield and yield components (total biomass, number of corms per plant, total corm mass per plant) were measured at harvest. Biomass was measured by weighing the shoots together with roots which are corms in taro, corms were individually counted to get the corm number and corm mass was measured by weighing the corms only.

3.1.5 Agronomic practices

Prior to land preparation, soil samples were taken for soil fertility and textural analyses. At Ukulinga, land preparation involved ploughing, disking and rotovating to achieve fine soil particles. At Umbumbulu, land preparation only included ploughing and disking. Based on results of soil fertility analyses, fertiliser was applied using an organic fertiliser (Gromor Accelerator®), at a rate of 5 330 kg ha^{-1} (Mare, 2010), 133.25g/plants was applied during planting calculated based on plant population. The nutritional composition of Gromor Accelerator® is shown in table 3.2. Planting holes were opened with a hand-hoe and organic fertiliser was mixed with soil before one cormel was planted per hole. Periodic weeds and ridging were done by hand-hoeing.

Table 3.1: Soil sample test results prior to planting at Ukulinga and Umbumbulu

Sites	**P** mg/l	**K** mg/l	**Ca** mg/l	**Mg** mg/l	**pH** (kcl)	**Zn** mg/l	**Mn** mg/l	**Cu** mg/l	**Org. C %**	**N** %	**Clay** %
Ukulinga	**28**	**448**	**1611**	**789**	**4.99**	**4.1**	**5**	**6.7**	**2.1**	**0.25**	**36**
Umbumbulu	**6**	**92**	**358**	**142**	**4.10**	**1.6**	**3**	**1.3**	**3.6**	**0.23**	**38**

Table 3.2 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 Controlled Environment Experiment

3.2.1 Plant material

Dumbe dumbe and Dumbe omhlophe, eddoe type taro landraces were used for the controlled environment study. Landraces were characterised and sourced as described in section 3.1.1.

3.2.2 Description of controlled environment and experimental design

The controlled environment study was conducted in growth tunnels at the University of KwaZulu–Natal's Controlled Environment Facility (CEF). The environmental conditions inside the tunnel were semi-controlled (~33/18°/C day/night; 60–80% RH). The experiment was planted on the 5th of March 2014.

The experimental design was a split–plot design arranged in randomised complete blocks. The main plots were allocated to water regimes – 30 and 100% crop water requirement. The two taro landraces were considered as sub–plots with each individual plant representing a replicate. A plant spacing of 0.5 m x 0.5 m was used for the experiment. Irrigation scheduling was based on reference evapotranspiration (ET_o) and a crop factor (K_c) (Allen et al., 1998). Taro can take up to 7 months (210 days) to mature and authors differ on how these may be divided based on growth stages (Mabhaudhi, 2012). Crop coefficient (Kc) values for taro were as described by Fares (2008) whereby Kc initial = 1.05 (2 months), Kc med = 1.15 (4months) and Kc late = 1.1 (1 month). Using these values of Kc and ET_o crop water requirement (ETa) was then calculated as described by Allen et al. (1998):

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

where, ETa = crop water requirement,

ET_o = reference evapotranspiration, and

K_c = crop factor.

3.2.3 Data collection

Data collection for crop growth, development and yield parameters was as described Section 3.1.4. Soil water content was measured weekly using an ML–2X Theta Probe connected to an HH2 handheld moisture meter (Delta-T Devices, UK).

3.2.4 Agronomic practices

Soil samples were taken from tunnel beds before planting and submitted for soil fertility and texture analyses. Based on soil fertility results, an organic fertiliser Gromor Accelerator® (133, 25 g) was applied per planting station. Propagules were first treated with bactericide and fungicide (Sporekill®) to prevent rotting during sprouting. Routine hand weeding was done in the tunnels.

Table 3.3: Soil sample test results prior to planting at Controlled Environment Facility

Site	**P** mg/l	**K** mg/l	**Ca** mg/l	**Mg** mg/l	**pH** (kcl)	**Zn** mg/l	**Mn** mg/l	**Cu** mg/l	**Org. C %**	**N** %	**Clay** %
Tunnel beds	**100**	**296**	**2413**	**350**	**5.09**	**23.5**	**44**	**6.4**	**3.3**	**0.32**	**38**

3.3 Statistical Analyses

All data were subjected to analysis of variance (ANOVA) using GenStat® (Version 14, VSN International, UK). Means of significantly different variables were separated using least significant differences (LSD) at a probability level of 5%.

CHAPTER 4

RESULTS: FIELD PERFORMANCE OF TARO LANDRACES [*COLOCACIA ESCULENTA* (L.) SCHOTT] UNDER RAINFED CONDITIONS

4.1 *Emergence*

Highly significant differences ($P<0.001$) were observed between taro landraces with respect to emergence (Figure 4.1). The interaction between landraces and planting densities was also significant ($P <0.05$). For all planting densities, the highest emergence rate was observed in the Dumbe pondo (DP) landrace followed by Dumbe omhlophe (DO) and Dumbe dumbe (DD), respectively (Figure 4.1a & b). Final emergence differed with planting density between the landraces. In addition, the final emergence for DD and DP was high in the planting density of 1 m x 0.5 m while DO had high final emergence under 1 m x1 m planting density (Figure 4.1a & b).

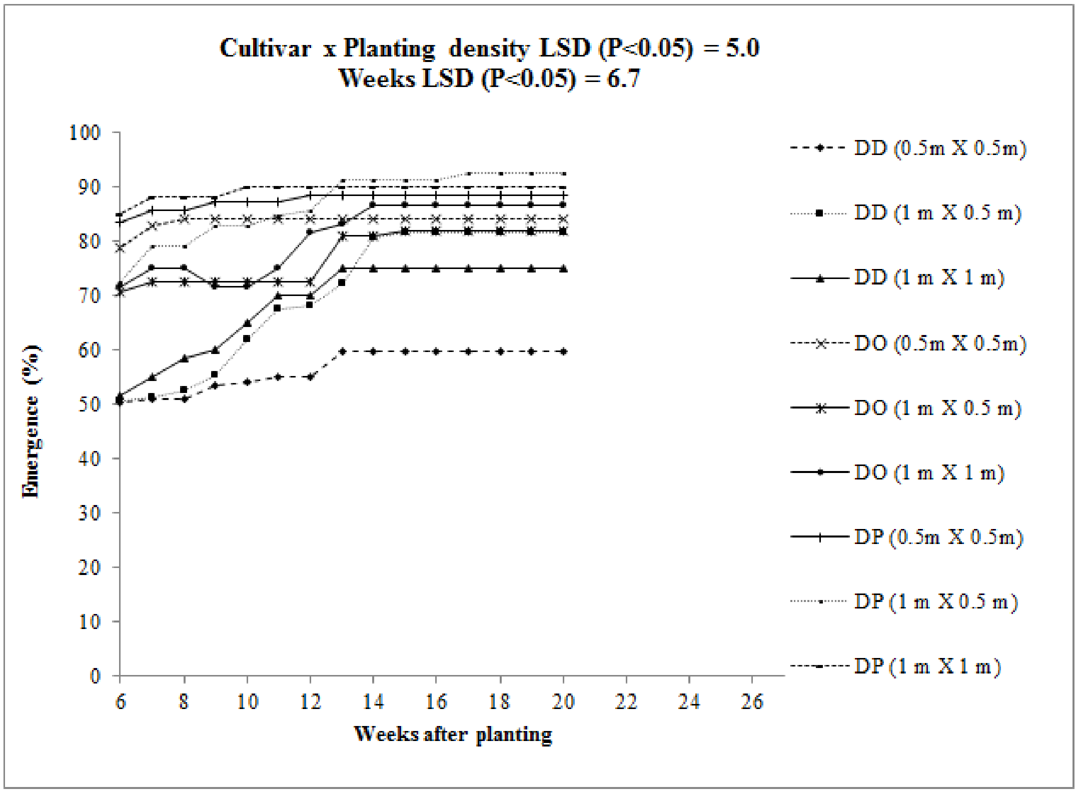

Figure 4.1 (a): Emergence of three taro landraces (Dumbe dumbe, Dumbe pondo and Dumbe omhlophe) grown at Ukulinga research station.

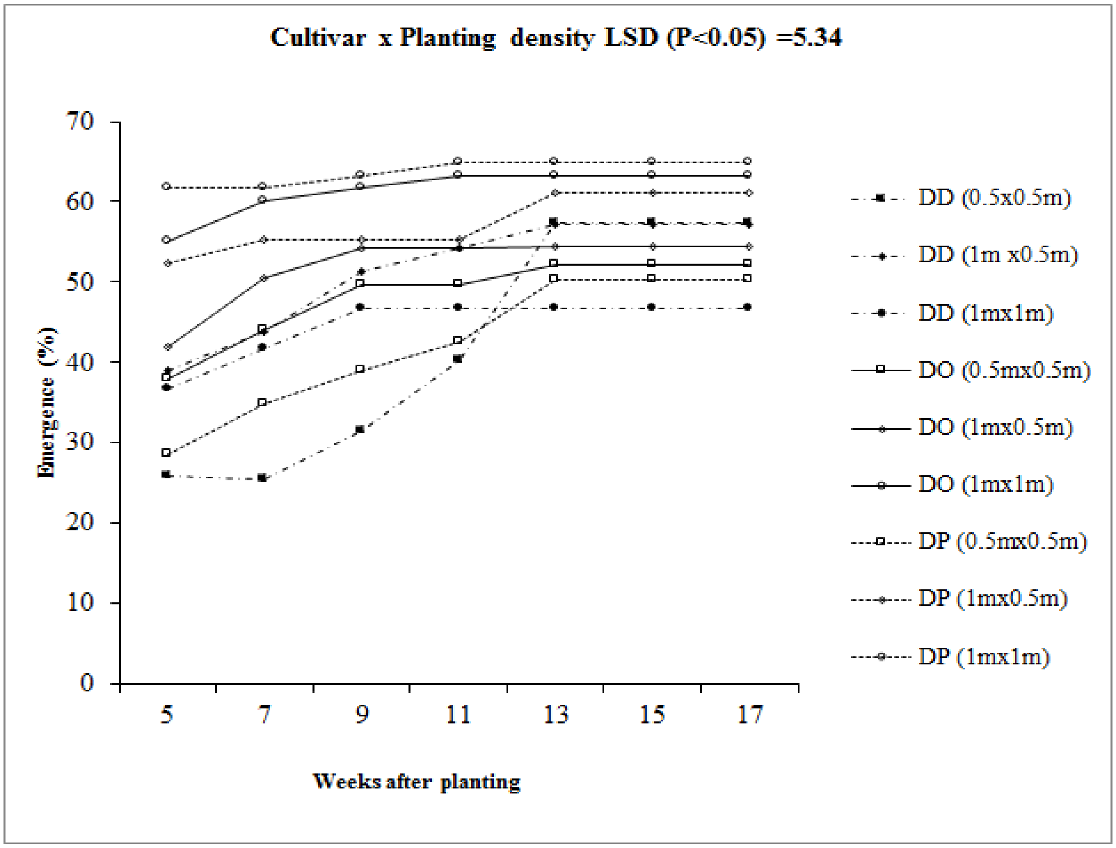

Figure 4.1 (b): Emergence of three taro landraces (Dumbe dumbe, Dumbe pondo and Dumbe omhlophe) grown at Umbumbulu area.

4.2 Growth parameters

4.2.1 Plant height

There were highly significant differences (P<0.001) between landraces with regards to plant height in both sites. The interaction between landraces and planting densities for plant height at Umbumbulu (Figure 4.2b) was highly significant (P<0.001). There were no significant differences (P>0.05) observed between planting densities at Ukulinga for plant height (Figure 4.2a). Dumbe pondo was significantly taller (P<0.001) than Dumbe omhlophe and Dumbe dumbe at both sites. However, DO and DD were statistically similar at Ukulinga

Ukulinga

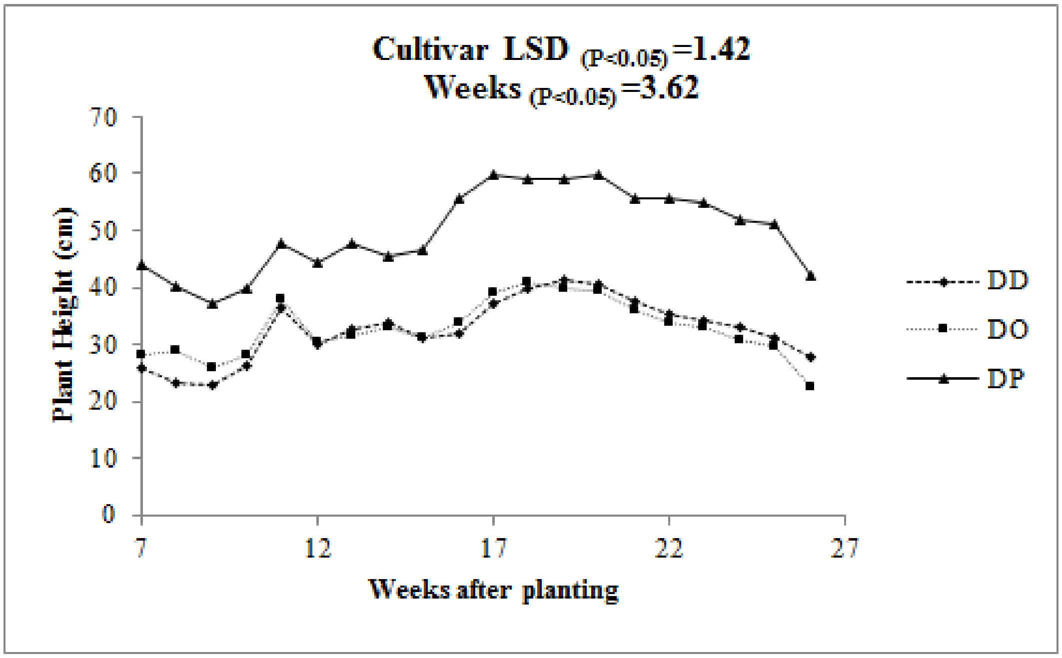

Figure 4.2 (a): Plant height (cm) of three taro landraces [Dumbe dumbe (DD), Dumbe pondo (DP) and Dumbe omhlophe (DO)] grown at Ukulinga research station.

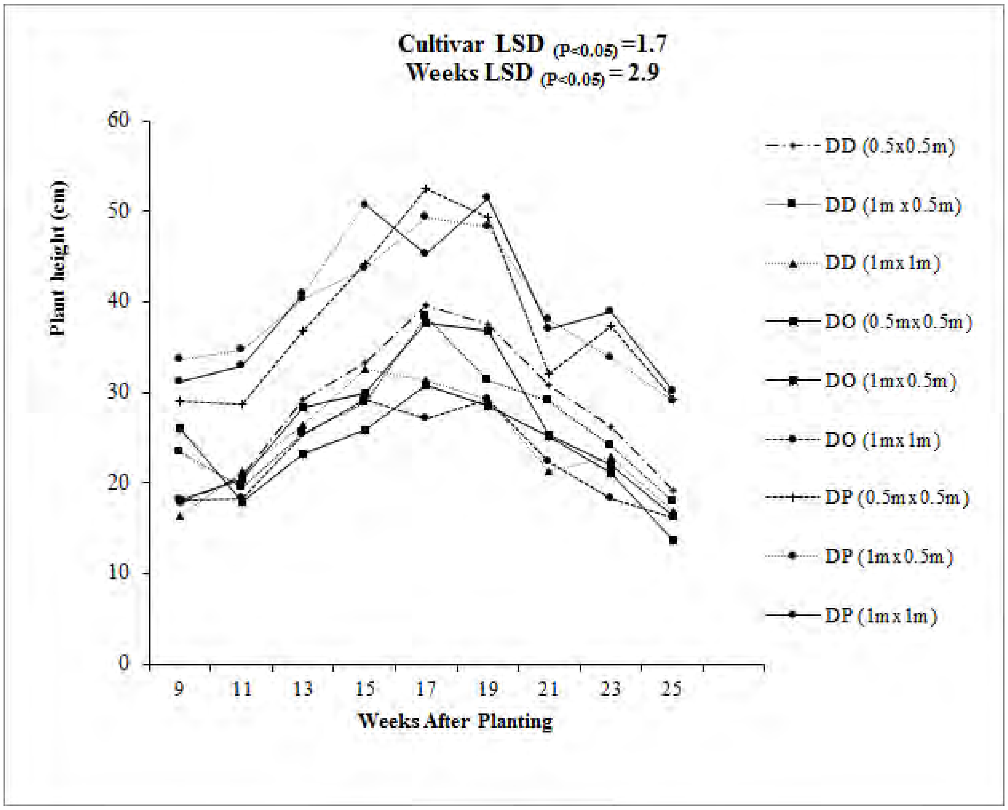

Figure 4.2 (b): Plant height (cm) of three taro landraces [Dumbe dumbe (DD), Dumbe pondo (DP) and Dumbe omhlophe (DO)] grown at Umbumbulu area.

4.2.2 Leaf number

Taro landraces exhibited highly significance differences (P<0.001) for leaf number. Results showed that the interaction of planting density and landraces over time was not significant (P>0.05) (Figure 4.3a & b). It was observed that leaf number decreased with time from 7 to 26 weeks after planting. However, the final leaf number was high in Dumbe omhlophe landrace compared to Dumbe dumbe and Dumbe pondo for all planting densities. Results of leaf number measured at Ukulinga (Figure 4.3a) showed highly significant differences (P<0.001) between planting density and landraces, whereas at Umbumbulu (Figure 4.3b) no significant differences (P>0.05) were observed

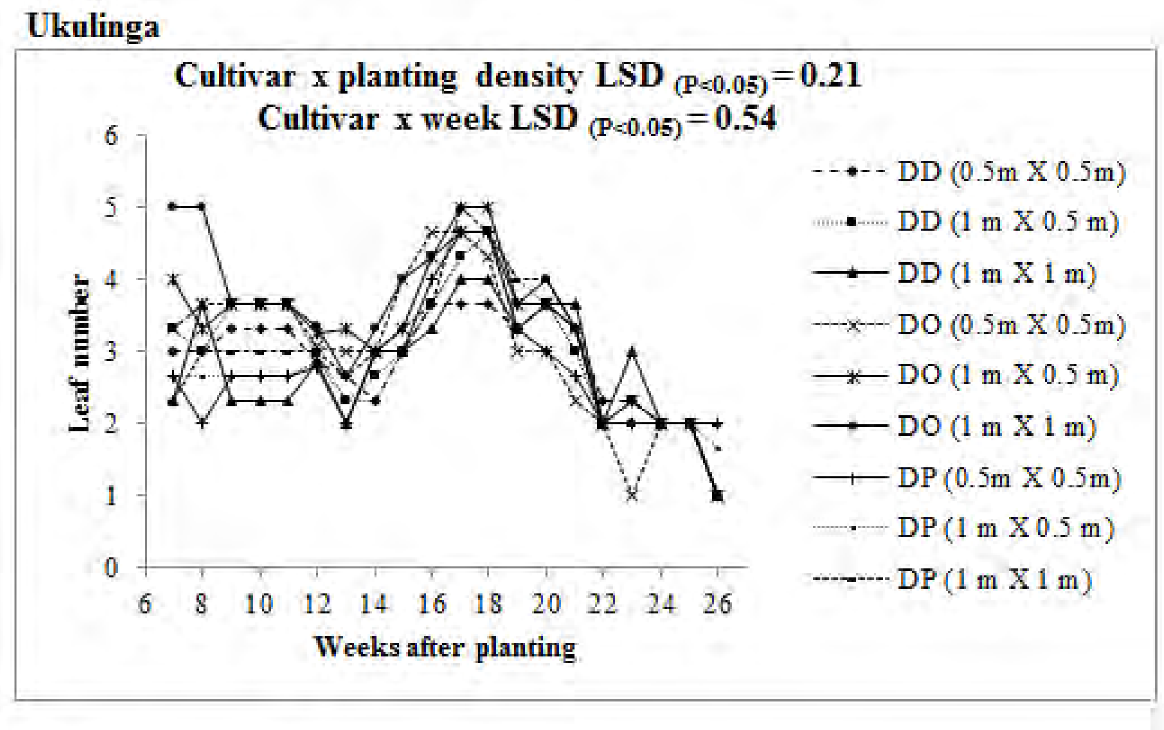

Figure 4.5 (a): Leaf number of three taro landrace [Dumbe dumbe (DD), Dumbe pondo (DP) and Dumbe omhlophe (DO)] grown at different planting densities at Ukulinga research station.

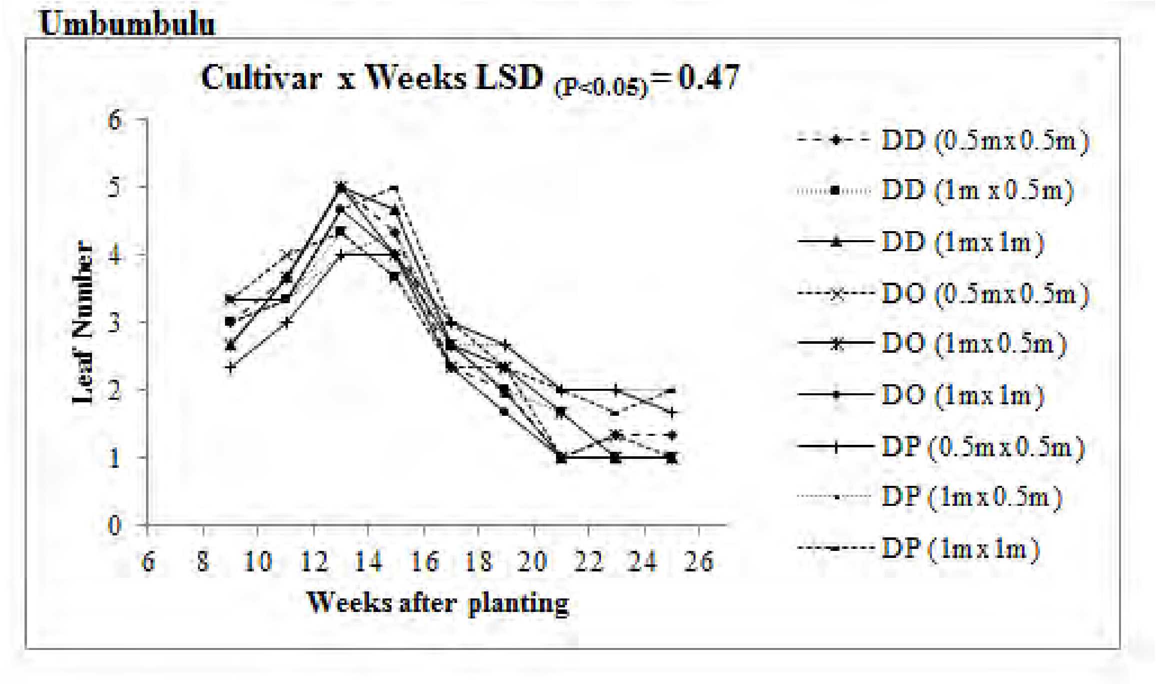

Figure 4.6 (b): Leaf number of three taro landrace [Dumbe dumbe (DD), Dumbe pondo (DP) and Dumbe omhlophe (DO)] grown at different planting densities at Umbumbulu area.

4.2.3 Chlorophyll content index

Taro landraces were shown to differ significantly ($P<0.001$) with respect to CCI .Dumbe dumbe landrace had the highest final CCI compared to DP and DO landraces, respectively, at Ukulinga (Figure 4.4a). Results of CCI showed that DO had the greatest decrease (40%) at week 23 at Ukulinga and also at Umbumbulu (Figure 4.4b) a similar pattern was observed.

Ukulinga

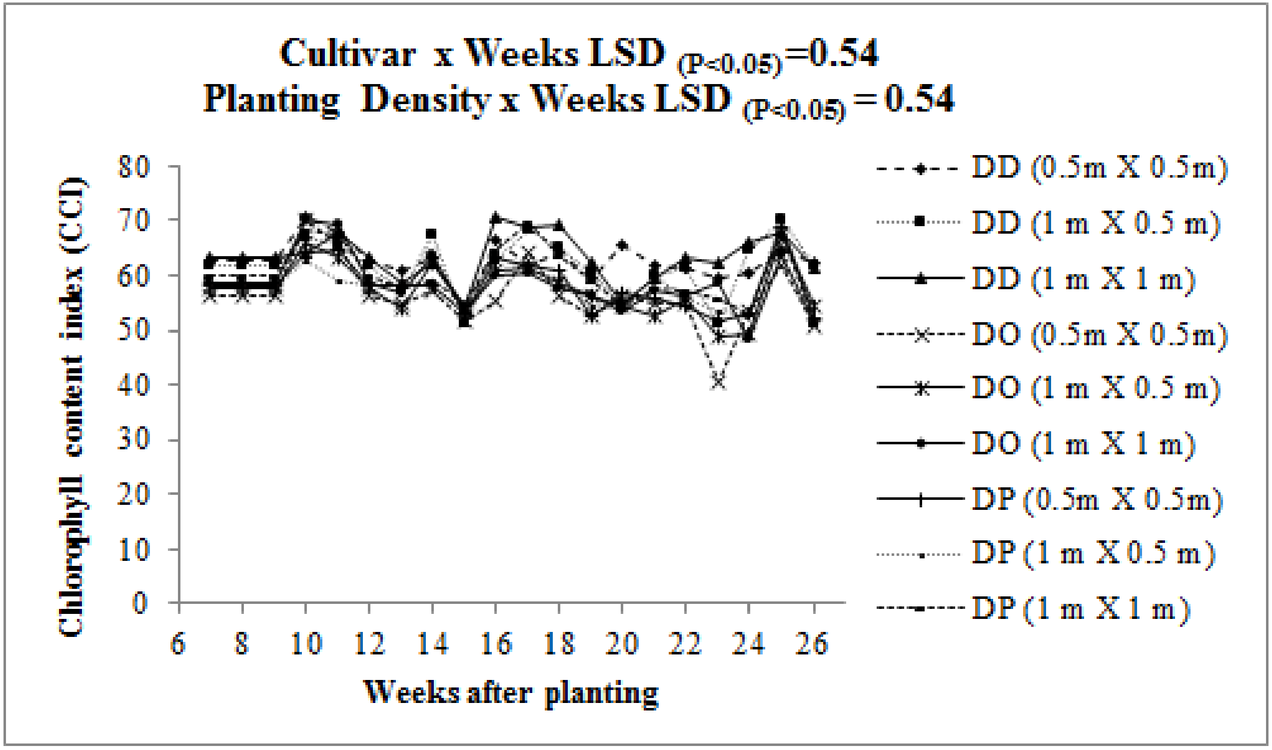

Figure 4.7 (a): Chlorophyll content index (CCI) of three taro landraces [Dumbe dumbe (DD), Dumbe pondo (DP) Dumbe omhlophe (DO)] grown at different planting densities at Ukulinga

Umbumbulu

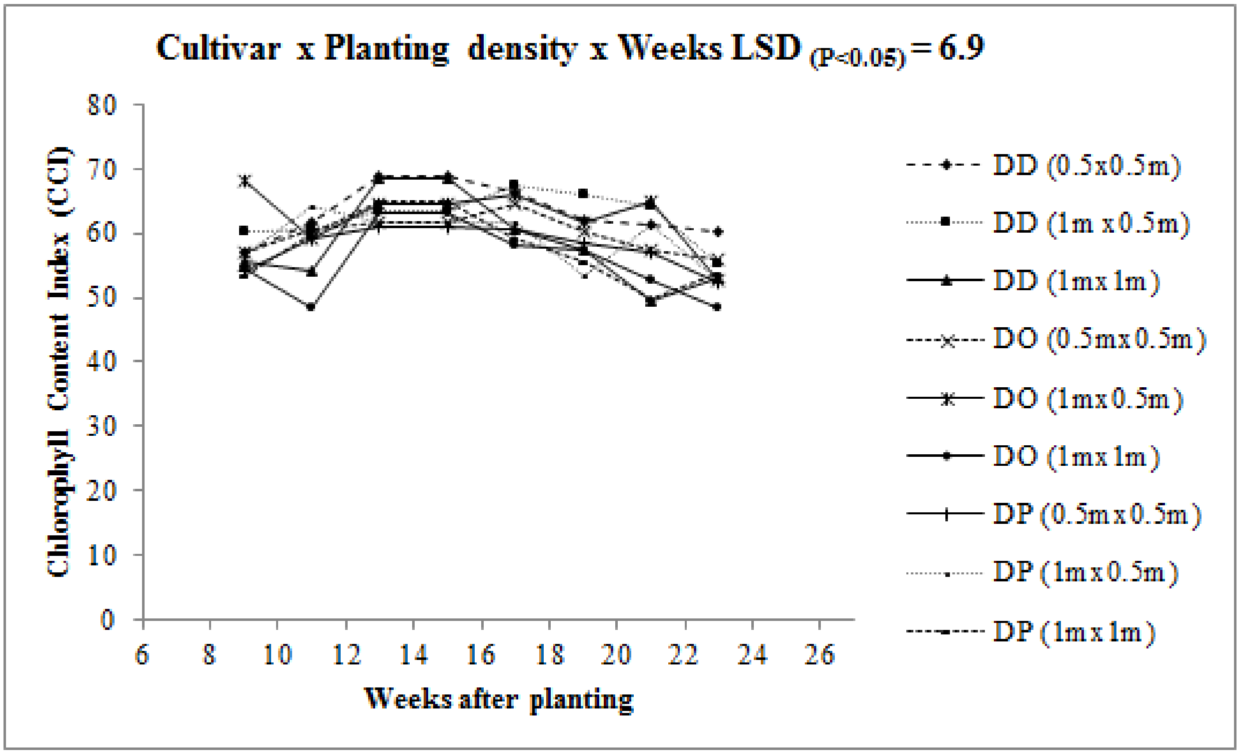

Figure 4.8 (b): Chlorophyll content index (CCI) of three taro landraces [Dumbe dumbe (DD), Dumbe pondo (DP) and Dumbe omhlophe (DO)] grown at different planting densities at Umbumbulu

4.3 Yield and yield parameters

Results recorded for biomass, corm mass and corm number for Ukulinga and Umbumbulu exhibited a similar trend for the different planting densities (Table 4.1). Yield varied significantly ($P<0.05$) under different planting densities at both planting sites (Table 4.1). At Umbumbulu, planting taro at a spacing of 0.5 m x 0.5 m significantly ($P<0.05$) improved corm yield (4.708 t/ha) compared to when planted at a spacing of 1 m x 1m (1.659 t/ha) and 1 m x 0.5 m (2.761t/ha). The results recorded at Ukulinga also followed the same trend. There was no significant difference ($P>0.05$) in corm yield between the spacing of 1 m x 0.5 m and 1 m x 1 m at Umbumbulu, and a similar pattern was observed at Ukulinga. Biomass varied significantly ($P<0.05$) in response to planting density. It was such that 0.5 m x 0.5 m (4.825 t/ha) > 1 m x 1 m (1.829 t/ha) > 1 m x 0.5 m. Corm number also varied significantly ($P<0.05$) between different planting densities at

Umbumbulu. The overall yield (t/ha) was higher under planting density treatment of 0.5 m x 0.5 m at both planting sites.

Table 4.1: Yield and yield components (biomass, corm mass and corm number) of three taro landraces [Dumbe dumbe (DD), Dumbe pondo (DP) & Dumbe omhlophe (DO)] grown at different planting densities at Ukulinga and Umbumbulu.

Density		0.5x 0.5m	1 m x 0.5 m	1 m x 1 m	LSD$_{(P>0.05)}$	CV%
Umbumbulu	Biomass (t/ha)	4.825b[1]	3.212ab	1.829a	2.02	28.93
	corm yield (t/ha)	4.708b	2.761a	1.659a	1.76	23.34
	Corm number/ha	61481b	38148a	20370a	21761	16.91
Ukulinga	Biomass (t/ha)	12.90b	7.15a	4.59a	2.76	6.00
	corm yield (t/ha)	10.39b	5.61a	3.68a	2.16	7.00
	Corm number/ha	145185.00c	70370.00b	38889.00a	22513	8.6

Note: Numbers followed by the same letter are not significantly different from each other at $p<0.05$

4.4 Discussion

Emergence differs according to planting densities and landrace type. The results showed that Dumbe pondo had high emergence at low planting density (1 m x 1 m) compared to other planting densities used in this study (Figure 4.1a & b). This could be attributed to the fact that at low planting density there was low competition for plant growth requirements since there were few plants. The findings of this study were different from what Shange (2004) reported.

The results for plant height at Ukulinga showed no significant differences between planting densities (Figure 4.2a). These findings concur with reports by Tsedalu et al. (2014) who also observed that planting density had no effect on taro plants height. Gebre et al. (2015) explained that the lack of effect may be due to the fact that taro plant grow laterally instead of vertically by producing a greater number of suckers. Results observed at Umbumbulu, however, showed that planting density had an effect on plant height with low planting density (1 m x 1 m) having the tallest plants relative to medium (1 m x 0.5 m) and high density (0.5 m x 0.5 m), respectively (Figure 4.2a &b). This was in contrast to observations made at Ukulinga which concurred with reports in the literature.

Results of leaf number measured at Ukulinga site showed significant differences between planting density treatments and landraces (Figure 4.3a). The final leaf number for Dumbe omhlophe landrace was high at all planting densities compared to Dumbe dumbe and Dumbe Pondo, respectively. However, low planting density (1 m x 1 m) had the maximum number of leaves. These observations suggest that plants at low density were able to use growth resources more effectively compared to plants grown at higher plant density. Plants grown at high plant density were competing for resources and their leaves senesce early in order to contribute to corm formation to escape stress. The results of the current study are contrary to the findings of Abd-Ellatif et al. (2010) who reported maximum leaf number at high planting density. Planting density had no effect on taro leaf number at Umbumbulu site (Figure 4.3b). Similar results were reported by Tumuhimbise *et al*. (2009).

Landraces were shown to differ significantly with respect to CCI. Dumbe dumbe landrace had the highest final CCI compared to Dumbe pondo and Dumbe omhlophe landraces. Results of CCI showed that DO had the greatest decrease (40%) at week 23 at Ukulinga (Figure 4.4 a) and also at Umbumbulu (Figure 4.4b) a similar pattern was observed. This might be due to the fact that as taro is in maturity stage. In this stage, there is a leaf senescence period associated with decreasing root and shoot growth with continued increase in corm size as the crop matures (Sivan, 1982). The leaf development decreases in intensity and the plant growth is reduced (Silva *et al*., 2008). At this stage there is rapid decline in shoot growth and total shoot dry weight, and reduction in the number of active leaves.

Yield and yield components (biomass, corm mass and corm number) recorded at Ukulinga and Umbumbulu exhibited a similar trend within different planting densities (Table 4.1). Yield varied significantly with planting densities. Overall, yield was higher under planting density of 0.5 m x 0.5 m at both sites. These findings agreed with reports by Pardales and Villanueva (1984) on the effects of plant population on taro production. Previous studies done on taro by several researchers (Weber et al., 1966; Pardales et al., 1982; Pardales and Belmonte, 1984; Pardales, 1986) showed that corm yield increased with increase in population. Kagbo et al. (1973) suggested that the increase in yield was due to the higher number of plants per unit area, which intercept solar radiation and thereby enhanced photosynthesis on a unit area basis. Plucknett et al. (1970) further suggested that at high planting density, there was an added advantage of full ground cover which effectively suppressed weeds hence contributing to greater yield.

To conclude, planting densities had an effect on taro emergence. In addition, final emergence for Dumbe dumbe and Dumbe pondo was high at planting density of 1 m x 0.5 m while Dumbe omhlophe had high final emergence under 1 m x1 m planting density. Dumbe dumbe landrace had the highest final CCI compared to DP and DO landraces, at Ukulinga site. Dumbe omhlophe had maximum leaf number compared to DD and DP for all planting densities. Planting taro at a spacing of 0.5 m x 0.5 m significantly improved corm yield.

CHAPTER 5

RESULTS: GROWTH RESPONSE OF SELECTED TARO LANDRACES TO DIFFERENT IRRIGATION REGIMES UNDER CONTROLLED ENVIRONMENT

5.1 *Crop establishment*

Results of crop emergence showed differences between varieties (Figure 5.1), although it was not statically different (P>0.05). Water availability had an effect (P<0.05) on emergence. The Dumbe dumbe (DD) landrace emerged better than Dumbe omhlophe (DO) landrace, reaching 100% emergence within 5 Weeks After Planting (WAP) at 100 ETa compared to 70% emergence recorded for the DO landrace over the same period. The DD landrace had the final lowest emergence percentage (85%) and DO (98%) at 30% ETa.

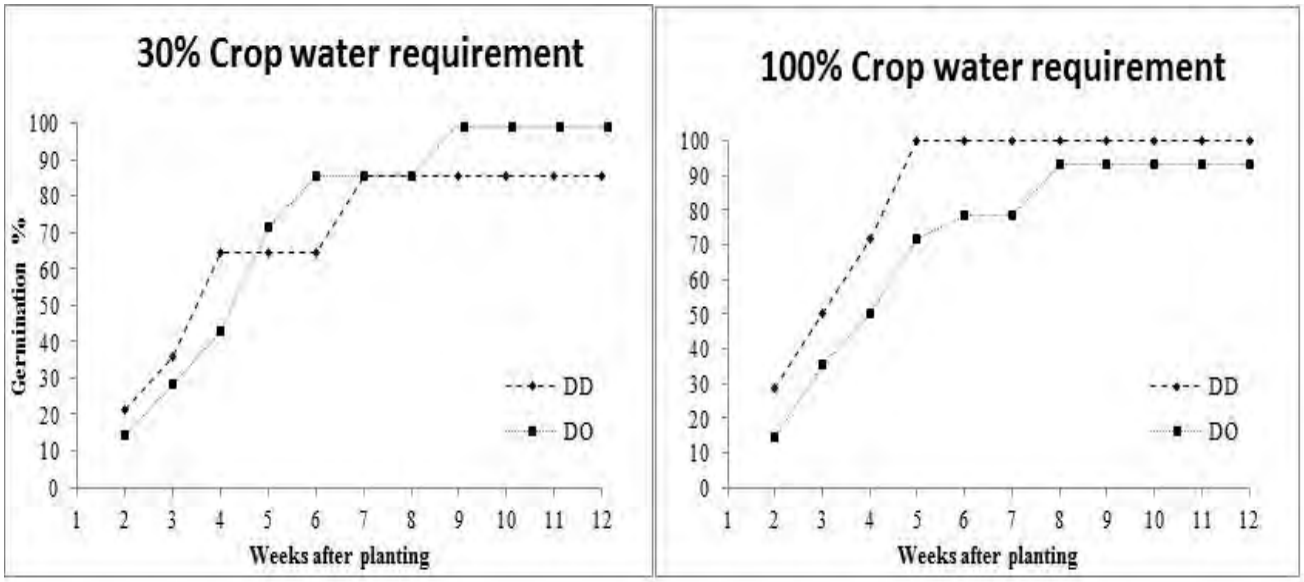

Figure 5.1: Emergence of two taro landraces [Dumbe dumbe (DD) and Dumbe omhlophe (DO)] in response to two levels of irrigation (30% and 100% ETa) under controlled environment conditions.

5.2 *Plant height*

There were highly significant differences (P<0.001) between landraces with regards to plant height (Figure 5.2). The interaction between water regimes and landraces over time was highly significant (P<0.001). However, the interaction between water regimes and landraces was not significant (P>0.05). The trend showed that there was a steady increase in plant height of the DD landrace and while plant height for the DO landrace tended to fluctuate over time (Figure 5.2). Based on mean values of plant height across water regimes, the DD landrace had taller plants than DO landrace.

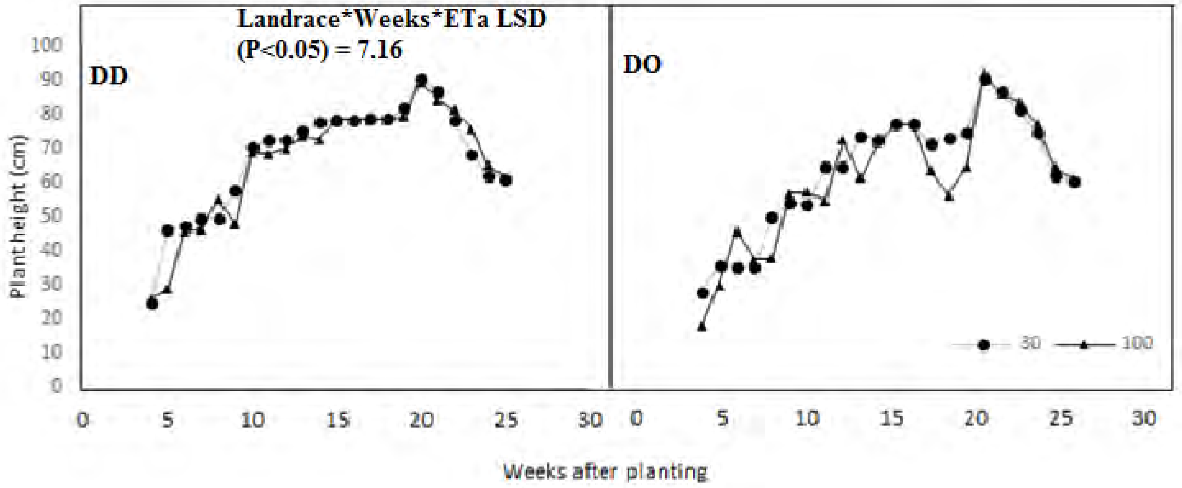

Figure 5.2: Plant height of taro landraces [Dumbe dumbe (DD) and Dumbe omhlophe (DO)] in response to two levels of irrigation (30% and 100% ETa) under controlled environment conditions.

5.3 *Leaf number*

Taro landraces showed highly significances difference (P<0.001) with respect to leaf number. Unlike plant height, the interaction between water regimes and landraces over time was not significant (P>0.05) (Figure 5.3). A sharp decrease in leaf number was observed from 20 WAP in DO the landrace at 100% Eta; similar to plant height, leaf number of the DO landrace also fluctuated over time. A similar trend was observed for the DD landrace for both water regimes (30% and 100% ETa). It was interesting to observe a sudden decrease in leaf number at high water regimes.

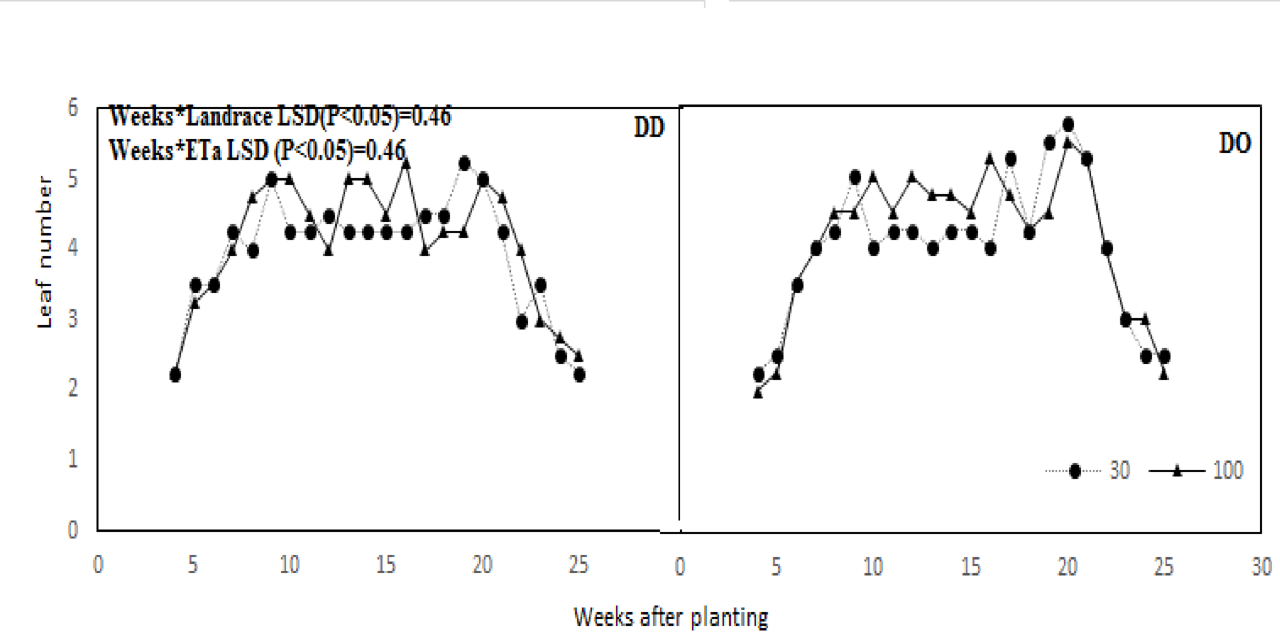

Figure 5.3: Leaf number of taro landraces [Dumbe dumbe (DD) and Dumbe omhlophe (DO)] in response to two levels of irrigation (30% and 100% ETa) under controlled environment conditions.

5.4 *Chlorophyll content index*

Highly significant differences (P<0.001) were observed for chlorophyll content index (CCI) over time (Figure 5.4). The interaction between water regimes and landraces over time was not significant (P>0.05). Chlorophyll content index was shown to decrease (42%) at 10 WAP at 30% ETa while it increased (60%) at 100% ETa over the same period. Interestingly, CCI was higher at 30% ETa compared to 100% ETa.

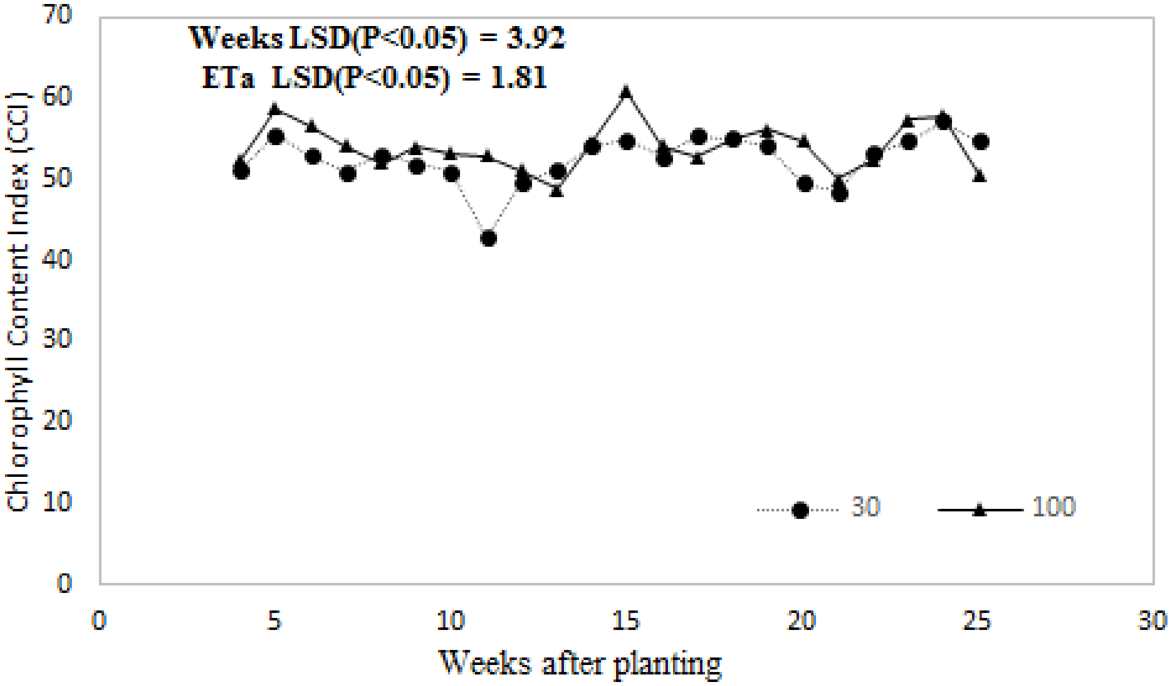

Figure 5.4: Chlorophyll content index (CCI) of taro landraces (DD) and DO) in response to two levels of irrigation (30% and 100% ETa) under controlled environment conditions.

5.5 *Soil water content*

Results of soil water content (SWC) varied significantly ($P<0.001$) between water regimes, with SWC being higher for the 100% ETa treatment relative to the 30% ETa treatment (Figure 5.5). Soil water content was constant (20%) from 4th WAP up to 16 WAP at 30% ETa; SWC increased slightly (23%) at 18 WAP. This trend was observed up to end of the study. The SWC was significantly higher (44%) at 100 ETa, from 4 WAP until the final week.

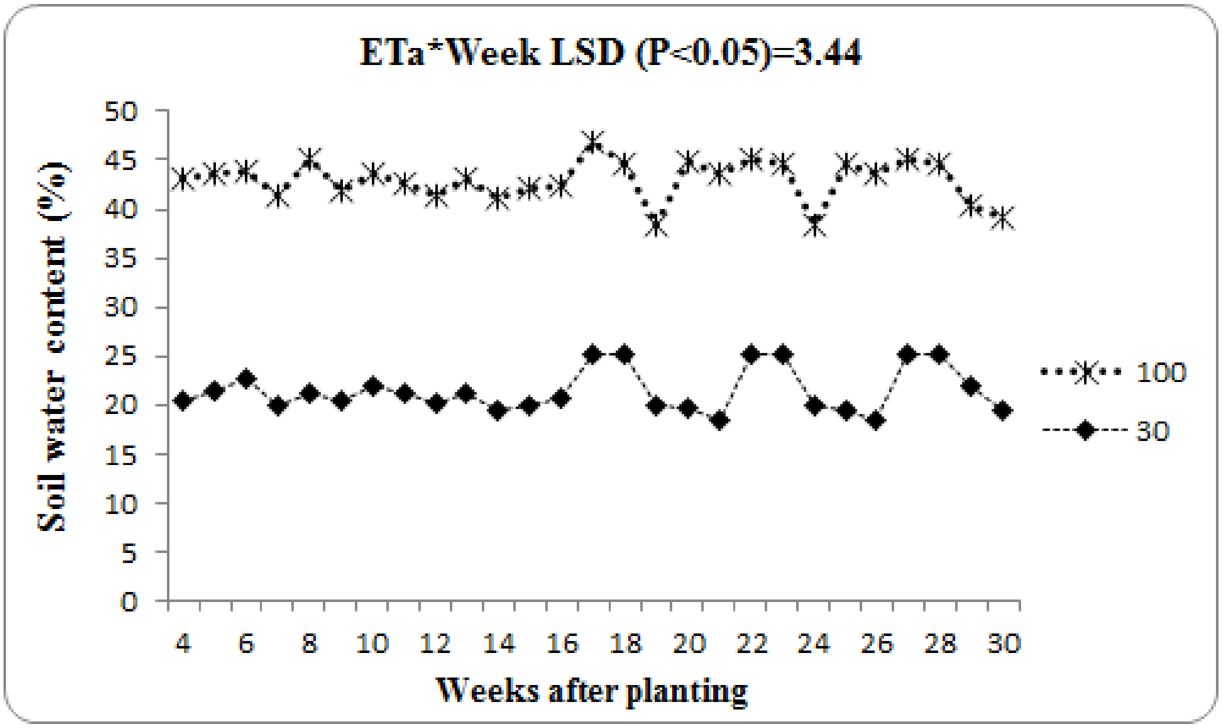

Figure 5.5: Soil water content (SWC) of taro landraces [Dumbe dumbe (DD) and Dumbe omhlophe (DO)] in response to two levels of irrigation (30% and 100% ETa) under controlled environment conditions.

5.6 *Yield and yield components*

Results for biomass, corm mass and corm number, showed that taro landraces responded differently to different water regimes (Table 5.1). Yield varied significantly ($P<0.05$) between the two landraces (Table 5.1) Corm mass per plant also differed significantly ($P<0.05$) between water regimes. Water regimes had significant effect ($P<0.05$) on biomass, corm mass and corm number (Table 5.1). Dumbe omhlophe had the highest biomass under both water regimes compared to DD. However, DO performed the best at 30% ETa in terms of biomass. Dumbe dumbe had the highest corm mass (1.88 kg/plant) at 30% ETa while at 100% ETa it had the low corm mass (1.07 kg/plant). Dumbe dumbe produced more corms (21) at 30% ETa than at 100% ETa (10) (Table 5.1).

Table 5.1: Yield and yield components (biomass, corm mass and corm number) of two taro landraces [Dumbe dumbe (DD) and Dumbe omhlophe (DO)] grown under controlled environment conditions at 30 and 100% ETa.

Water regime*	Landraces	Biomass (kg/plant)	Corm mass (kg/plant)	Number of corms
30%	DD	2.61a	1.88b	21.00b
	DO	4.40b	1.16a	13.12a
100%	DD	3.09a	1.07a	10.25a
	DO	3.52b	1.53ab	17.12b
Mean		3.41	1.41	15.38
LSD(P>0.05)		1.11	0.50	5.60
CV%		11.4	10.1	15.5

*number represents percentage of crop water requirement
1 Numbers followed by the same letter are not significantly different from each other at $p<0.05$

5.3. Discussion

Soil water content varied significantly between water regimes with the 100% ETa having higher SWC than the 30% ETa water regime. This was true to expectation. Emergence results showed that water availability had an effect on taro emergence (Figure 5.1). Taro emerged faster under non-stress relative to water stress conditions. Dumbe dumbe had better emergence than the DO landrace. However, the DD landrace had low emergence at 30% ETa. Studies by Sunitha et al.

(2013) revealed that within 45 days, 77% of corms sprouted with drip irrigation whereas only 22% of corms sprouted without irrigation.

Plant height showed significant differences between irrigation treatments, and there were significant differences between landraces (Figure 5.2). Dumbe dumbe had tall plants at 30% ETa and also at 100% ETa. Similar findings were observed by Mabhaudhi et al. (2013). Taro landraces showed a sharp decline in leaf number from 20 weeks after planting while leaf number also tended to fluctuate. The fluctuations in plant height and leaf number are because as taro grows, it continuously shades and replaces leaves. This often results in measurements of leaf and plant height fluctuating and similar findings were also observed by Mabhaudhi et al. (2013). Chlorophyll content index varied significantly over time. This variation over time explains why CCI can be used as maturity index as it tends to increase during the vegetative stages and decreases as the crop matures. Contrary to reports in the literature (Mabhaudhi et al., 2013), our results showed that CCI was higher at 30% ETa compared to 100% ETa. The expectation is usually that CCI will decrease under water stress as a down regulation of photosynthesis.

Yield and yield parameters (biomass, corm mass and corm number) results showed that landraces responded differently to water availability (Table5.1). The corm mass of DD landrace was higher at 30% ETa compare to 100 ETa. These findings differ from a study reported by Uyeda et al. (2011) on growth responses of taro grown under different water regimes. The DO landrace responded differently to DD landrace, at 100% ETa corm mass was higher than in 30% ETa. These results concur with the study conducted Byrd et al. (2014) who reported similar findings of limited water availability during growth affects corm formation hence negatively impacting on yield.

CHAPTER 6

GENERAL DISCUSSION AND CONCLUSION

6.1 Introduction

Taro *(Colocasia esculenta* L. Schott) is one of the edible aroids (Shange, 2004; Lebot, 2009). Aroids are generally known for their relatively high water requirement (Sunitha et al, 2013) although there have been reports of adaptation to low water availability in upland taro varieties (Mabhaudhi et al., 2014). Taro is a widely distributed food crop that is generally grown throughout the tropics and subtropics (Villanueva and Abenoja, 1984; Kay, 1987; Modi, 2007). It is planted as a summer crop in temperate regions and is adapted to wetland environments. It is grown under a range of environments which include flooded, irrigated, rainfed and upland conditions where no flooding exists (Plucknett et al., 1970; Modi, 2007). Under rainfed conditions, taro can take 6 to 12 months to reach maturity (Miyasaka et al., 2003; Modi, 2007). It is a traditional crop in South Africa, mostly produced by rural communities for subsistence use. Although taro is associated with high levels of water-use, in South Africa, most of taro production is rainfed and occurs inland under water limited conditions (Modi, 2004; Mabhaudhi, 2012). Since it is one of the neglected crops, more agronomic knowledge is required regarding its production in local conditions. The aim of this study was to determine the effect of planting density on growth and yield of taro landraces from KwaZulu–Natal.

6.2 Challenges

- Animal attacks on taro which decreased the experimental plants.
- Hail damage at twelve weeks after planting (vegetative stage), which resulted in delayed corm formation, maturity, and reduction of yield.

6.3 Future lessons and research possibilities

The following recommendations may be made, based on observations made during the study;

- A high plant density (0.5 x 0.5 m) is recommended to farmers planting taro

- Farmers in areas that are prone to drought or low rainfall areas are encouraged to use the DD landrace
- This study did not evaluate the quality of yield; therefore future studies should consider yield quality as it is an important parameter
- Fertiliser application is also a key agronomic practice that needs to be evaluated in future studies

6.4 Final comments and summary conclusions

Chapter 4 evaluated the effect of planting density on growth and yield of taro landraces. Planting density is one of the most important factors that affect yield. This was confirmed by the results of this study which showed that taro yields increased with increasing plant density for all landraces. Yield and yield parameters (biomass, corm mass and corm number) recorded at Ukulinga and Umbumbulu exhibited a similar trend with respect to plant density. Planting taro in a spacing of 0.5 m x 0.5 m significantly improved corm yield. Interestingly, planting density seemed to have an effect on emergence; final emergence for DD and DP was high when planted at 1m x 0.5 m while DO had high final emergence when planted at 1 m x 1 m. The DD landrace had the highest final CCI compared to DP and DO landraces, at Ukulinga site. Dumbe omhlophe had higher leaf number compared to DD and DP for all three planting densities (0.5 m x 0.5 m, 1 m x 0.5 m and 1 m x 1m).

Chapter 5 focussed on the response of taro to different irrigation regimes under controlled environment conditions. The experiment only considered two landraces, DD and DO, due to the morphology of DP which made it difficult to grow in the tunnel beds. Results of plant emergence showed that water regimes had an effect on emergence with taro landraces emerging faster under non–stress relative to stress conditions. The DD landrace had better emergence than DO landrace. Plant height showed significant differences between irrigation treatments, and there were significant differences between landraces. Plant height was lower under water stress (30% ETa) relative to non-stress (100% ETa) conditions. The Dumbe dumbe landrace was shown to perform better than DO landrace under both water regimes suggesting that it was more adapted to water limited conditions. These differences between water regimes and landraces also translated to yield. Yield was higher under non-stress relative to water stress conditions. The DD landrace had higher yield than DO landrace at 30% ETa, again confirming its adaptability to water limited conditions.

To conclude, planting density had an effect on growth, development and yield of taro landraces. Plant spacing of 0.5 m x 0.5 m produced high yields at both Ukulinga and Umbumbulu. Water stress negatively affected growth and yield of taro landraces. With respect to the landraces, the DD landrace was shown to perform well under the range of environments considered in this study. The Dumbe omhlophe landrace also did better in different environments and the yields were higher in non-stress conditions, which shows that this landrace can give high yield in high rainfall areas.

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APPENDICES

Appendix 1: Analysis of variance tables for chapter 4

Ukulinga

Variate: Emergence %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	165.1	82.6	0.53	
Rep.*Units* stratum					
Cultivar	2	40855.0	20427.5	132.05	<.001
PD	2	850.9	425.5	2.75	0.066
Weeks	15	19560.7	1304.0	8.43	<.001
Cultivar.PD	4	5592.6	1398.1	9.04	<.001
Cultivar.Weeks	30	2760.9	92.0	0.59	0.956
PD.Weeks	30	2515.2	83.8	0.54	0.977
Cultivar.PD.Weeks	60	1351.9	22.5	0.15	1.000
Residual	286	44242.4	154.7		
Total	431	117894.8			

Variate: Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1729.57	864.78	18.43	
Rep.*Units* stratum					
Cultivar	2	35541.86	17770.93	378.71	<.001
PD	2	213.80	106.90	2.28	0.104
Week	19	16545.58	870.82	18.56	<.001
Cultivar.PD	4	335.03	83.76	1.78	0.131
Cultivar.Week	38	2020.67	53.18	1.13	0.277
PD.Week	38	1265.87	33.31	0.71	0.901
Cultivar.PD.Week	76	1744.04	22.95	0.49	1.000
Residual	358	16799.19	46.93		

Total	539		76195.62

Variate: Leaf number

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		1.5254	0.7627	2.26	
Rep.*Units* stratum						
Cultivar	2		14.4410	7.2205	21.43	<.001
PD	2		2.8670	1.4335	4.25	0.015
Week	18	(1)	351.2008	19.5112	57.91	<.001
Cultivar.PD	4		4.6098	1.1525	3.42	0.009
Cultivar.Week	36	(2)	43.6791	1.2133	3.60	<.001
PD.Week	36	(2)	15.6302	0.4342	1.29	0.131
Cultivar.PD.Week	72	(4)	21.3229	0.2962	0.88	0.743
Residual	340	(18)	114.5459	0.3369		
Total	512	(27)	568.9045			

Variate: Chlorophyll Content Index

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		134.38	67.19	3.66	
Rep.*Units* stratum						
Cultivar	2		2658.18	1329.09	72.30	<.001
PD	2		318.37	159.19	8.66	<.001
Week	15	(4)	8796.65	586.44	31.90	<.001
Cultivar.PD	4		84.23	21.06	1.15	0.335
Cultivar.Week	30	(8)	1510.50	50.35	2.74	<.001
PD.Week	30	(8)	937.88	31.26	1.70	0.015
Cultivar.PD.Week	60	(16)	1130.87	18.85	1.03	0.433
Residual	286	(72)	5257.41	18.38		

Total	431	(108)	20167.74

Yield

Variate: Biomass yield (t/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	4.438	2.219	0.29	
Reps.*Units* stratum					
CV	2	23.171	11.585	1.52	0.249
Density	2	325.534	162.767	21.37	<.001
CV.Density	4	1.419	0.355	0.05	0.995
Residual	16	121.893	7.618		
Total	26	476.455			

Variate: Corm yield (t/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	3.791	1.895	0.41	
Reps.*Units* stratum					
CV	2	14.291	7.146	1.53	0.247
Density	2	215.162	107.581	23.00	<.001
CV. Density	4	1.013	0.253	0.05	0.994
Residual	16	74.846	4.678		
Total	26	309.104			

Variate: Number of corms (ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	9.556E+08	4.778E+08	0.94	
Reps.*Units* stratum					
CV	2	1.014E+10	5.072E+09	9.99	0.002
Density	2	5.366E+10	2.683E+10	52.87	<.001
CV.Density	4	7.699E+09	1.925E+09	3.79	0.024
Residual	16	8.120E+09	5.075E+08		
Total	26	8.058E+10			

UMbumbulu

Variate: Emergence %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	3335.7	1667.8	13.78	
REP.*Units* stratum					
CV	2	3005.5	1502.7	12.41	<.001
PD	2	5143.9	2571.9	21.24	<.001
WKS	10	6758.3	675.8	5.58	<.001
CV.PD	4	5123.6	1280.9	10.58	<.001
CV.WKS	20	1075.5	53.8	0.44	0.982
PD.WKS	20	2081.4	104.1	0.86	0.638
CV.PD.WKS	40	928.5	23.2	0.19	1.000
Residual	196	23730.9	121.1		
Total	296	51183.2			

Variate: Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	336.10	168.05	5.49	
REP.*Units* stratum					
CV	2	10192.05	5096.02	166.50	<.001
PD	2	128.12	64.06	2.09	0.127
WKS	8	9297.59	1162.20	37.97	<.001
CV.PD	4	320.01	80.00	2.61	0.037
CV.WKS	16	391.33	24.46	0.80	0.685
PD.WKS	16	799.43	49.96	1.63	0.066
CV.PD.WKS	32	278.14	8.69	0.28	1.000
Residual	160	4897.17	30.61		
Total	242	26639.95			

Variate: Leaf number

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		0.6357	0.3178	1.24	
REP.*Units* stratum						
CV	2		4.3931	2.1965	8.58	<.001
PD	2		0.0548	0.0274	0.11	0.899
WKS	8		314.9787	39.3723	153.80	<.001
CV.PD	4		1.6448	0.4112	1.61	0.175
CV.WKS	16		14.0908	0.8807	3.44	<.001
PD.WKS	16		5.0958	0.3185	1.24	0.240
CV.PD.WKS	32		6.7619	0.2113	0.83	0.733
Residual	159	(1)	40.7028	0.2560		
Total	241	(1)	387.7562			

Variate: Chlorophyll Content Index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	14.45	7.22	0.39	
REP.*Units* stratum					
CV	2	357.64	178.82	9.54	<.001
PD	2	692.95	346.47	18.48	<.001
WKS	7	2558.22	365.46	19.49	<.001
CV.PD	4	274.78	68.70	3.66	0.007
CV.WKS	14	434.51	31.04	1.66	0.072
PD.WKS	14	955.93	68.28	3.64	<.001
CV.PD.WKS	28	366.85	13.10	0.70	0.866
Residual	142	2662.77	18.75		
Total	215	8318.10			

Yield

Variate: Biomass yield (t/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	16.246	8.123	2.01	
Reps.*Units* stratum					
CV	2	1.233	0.616	0.15	0.860
Density	2	40.468	20.234	5.00	0.021
CV.Density	4	5.251	1.313	0.32	0.857
Residual	16	64.744	4.046		
Total	26	127.941			

Variate: Corm yield (t/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	9.030	4.515	1.45	
Reps.*Units* stratum					
CV	2	0.770	0.385	0.12	0.884
Density	2	42.885	21.443	6.90	0.007
CV.Density	4	9.429	2.357	0.76	0.567
Residual	16	49.709	3.107		
Total	26	111.823			

Variate: Number of corms

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	7.969E+08	3.985E+08	0.84	
Reps.*Units* stratum					
CV	2	2.082E+09	1.041E+09	2.19	0.144
Density	2	7.652E+09	3.826E+09	8.07	0.004
CV.Density	4	3.457E+08	8.642E+07	0.18	0.944
Residual	16	7.590E+09	4.744E+08		
Total	26	1.847E+10			

Appendix 2: Analysis of variance tables for chapter 5

Controlled Environment Facility (CEF)

Variate: Emergence (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum					
CV	1	86.52	86.52		

REP.*Units* stratum			
ET	1	324.55	324.55
Weeks	10	29637.77	2963.78
CV.ET	1	403.84	403.84
CV.Weeks	10	505.49	50.55
ET.Weeks	10	1119.74	111.97
CV.ET.Weeks	10	1763.92	176.39
Total	43	33841.82	

Variate: Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	62.93	20.98	0.79	
REPS.*Units* stratum					
Landraces	1	1040.88	1040.88	39.33	<.001
WEEKS	21	98150.97	4673.86	176.62	<.001
ETA_%	1	309.94	309.94	11.71	<.001
Landraces.WEEKS	21	2791.26	132.92	5.02	<.001
Landraces.ETA_%	1	14.36	14.36	0.54	0.462
WEEKS.ETA_%	21	1650.62	78.60	2.97	<.001
Landraces.WEEKS.ETA_%	21	1631.80	77.70	2.94	<.001
Residual	261	6906.59	26.46		
Total	351	112559.34			

Variate: Leaf number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	0.7131	0.2377	1.07	
REPS.*Units* stratum					

WEEKS	21	262.3097	12.4909	56.17	<.001
Landraces	1	0.1392	0.1392	0.63	0.430
ETA_%	1	1.5028	1.5028	6.76	0.010
WEEKS.Landraces	21	12.9233	0.6154	2.77	<.001
WEEKS.ETA_%	21	19.8097	0.9433	4.24	<.001
Landraces.ETA_%	1	0.0256	0.0256	0.11	0.735
WEEKS.Landraces.ETA_%	21	4.2869	0.2041	0.92	0.568
Residual	261	58.0369	0.2224		
Total	351	359.7472			

__Variate: Chlorophyll Content Index__

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	3	204.44	68.15	2.13	
REPS.*Units* stratum					
WEEKS	21	2292.94	109.19	3.41	<.001
Landraces	1	9.17	9.17	0.29	0.593
ETA_%	1	231.82	231.82	7.24	0.008
WEEKS.Landraces	21	1043.14	49.67	1.55	0.061
WEEKS.ETA_%	21	799.36	38.06	1.19	0.261
Landraces.ETA_%	1	25.23	25.23	0.79	0.376
WEEKS.Landraces.ETA_%	21	1044.41	49.73	1.55	0.061
Residual	261	8357.50	32.02		
Total	351	14008.01			

__Variate: Soil Water Content (%)__

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	49.67	16.56	1.35	
Reps.*Units* stratum					

Landrace	1	61.80	61.80	5.05	0.025
ET	1	0.01	0.01	0.00	0.974
Weeks	26	477.45	18.36	1.50	0.059
Landrace.ET	1	0.08	0.08	0.01	0.937
Landrace.Weeks	26	315.56	12.14	0.99	0.480
ET.Weeks	26	1425.09	54.81	4.47	<.001
Landrace.ET.Weeks	26	438.05	16.85	1.38	0.108
Residual	321	3932.35	12.25		
Total	431	6700.06			

Yield

Variate: Biomass (kg)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	7	4.243	0.606	0.53	
Rep.*Units* stratum					
CV	3	13.823	4.608	4.06	0.020
Residual	21	23.861	1.136		
Total	31	41.927			

Variate: Corm Mass (kg)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	7	0.5668	0.0810	0.35	
Rep.*Units* stratum					
CV	3	3.3111	1.1037	4.78	0.011
Residual	21	4.8463	0.2308		
Total	31	8.7242			

Variate: Number of Corms

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	7	159.00	22.71	0.78	
Rep.*Units* stratum					
CV	3	528.25	176.08	6.08	0.004
Residual	21	608.25	28.96		
Total	31	1295.50			

Appendix 3: Experimental Design for field trials

Experimental Design (RCBD)

Block 1 (40 000 p/ha)	**Block 11 (20 000 p/ha)**	**Block 111 (10000p/ha)**
(0,5m X 0, 5 m)	**(1 m X 0, 5 m)**	**(1 m X 1 m)**

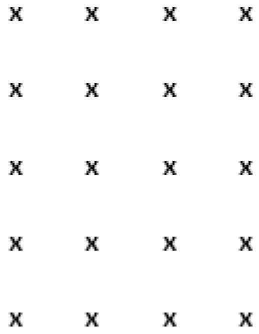
R1	**DO**	**DD**	**DP**	**DD**	**DP**	**DO**	**DP**	**DO**	**DD**
		1m							
R2	**DP**	**DO**	**DD**	**DO**	**DD**	**DP**	**DO**	**DD**	**DP**
		1 m							
R3	**DD**	**DP**	**DO**	**DP**	**DO**	**DD**	**DD**	**DP**	**DO**

3 Landraces of Dumbe Pondo (DP), Dumbe omhlophe (DO), and Dumbe dumbe (DD), Plot size of 4m X 3m =12m^2

Plot design

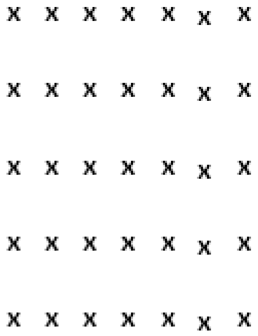
(1 m X 1 m)

20 plants



(1 m X 0, 5 m)

36 plants



(0,5m X 0, 5 m)

63 plants