Effect of intercropping and phosphorous application on the growth and yield of sweetpotato, groundnut and soybean.

BY

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Declaration

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted for obtaining any qualification.

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Abstract

Sweetpotato (*Ipomoea Batatas* (L) Lam) is among the most important root crops in Mozambique. However, the yield is lower than its genetic potential due to poor soil fertility and poor agronomic practices. Inorganic fertilizers that could contribute to yield increase are too costly hence they are not accessible. One of the feasible option is the use of intercropping with legumes to recapitalize soil fertility and improve yield. In this study the effect of intercropping sweetpotato with groundnut and soybean at three phosphorus (P) levels on soil chemical properties, sweetpotato, groundnut and soybean vegetative growth, yield and sweetpotato nutritional quality was investigated.

The study was carried out at Umbeluzi Research Station during the 2013/14, 2014/15 and 2015/16 growing seasons. A factorial design in a split plot arrangement was used. The main plot treatments were; sole sweetpotato, sole groundnut, sole soybean, sweetpotato-groundnut, sweetpotato-soybean, sweetpotato- groundnut- soybean and groundnut- soybean intercropping. The subplot treatments were 0, 20 and 40 kg P ha^{-1} applied at planting. Sweetpotato-groundnut, sweetpotato- soybean and soybean- groundnut intercropping at 40 kg P ha^{-1} in the 2015/16 growing season had more soil total nitrogen (N) compared to sole sweetpotato (P=0.038). Soybean-groundnut intercropping at 0 kg P ha^{-1} in 2013/14 growing season had more Olsen P than sole sweetpotato in all growing seasons (P=0.023). Sweetpotato- groundnut and sweetpotato- soybean had 21 % and 25.3 % more soil CEC respectively than sole sweetpotato at 40 kg P ha^{-1}. Sweetpotato- groundnut and sweetpotato- soybean intercropping at 40 kg P ha^{-1} had 42.9 % and 32.9 % more CEC than at 0 kg ha^{-1} respectively (P=0001). All treatments involving legumes in the mix had lower soil pH in 2014/15 and 2015/16 compared to 2013/14 growing seasons. Soybean- groundnut intercropping, sole groundnut and sole soybean had higher soil available potassium (K) compared to sole sweetpotato in 2015/16

growing season (P=0.001). Sweetpotato- soybean intercropping at 20 kg ha^{-1} had higher sweetpotato main stem length compared to sole sweetpotato. There was no significant difference in sweetpotato main stem length between 20 and 40 kg P ha^{-1} in the intercropping treatments (P>0.05). Sweetpotato- groundnut intercropping at 40 kg P ha^{-1} had higher fresh root mass plant $^{-1}$ compared to sole sweetpotato crop in 2013/14 and 2014/15 growing seasons. Sweetpotato-groundnut- soybean-, sweetpotato-soybean and sweetpotato- groundnut intercropping at 0 and 40 kg P ha^{-1} had higher number of leaves $plant^{-1}$ compared to sole sweetpotato. Sole sweetpotato had higher sweetpotato stem diameter compared to sweetpotato-soybean intercropping in 2013/14 and 2014/15 growing seasons. Sweetpotato- groundnut intercropping at 0 and 20 kg P ha^{-1} had 32.7 % and 58.5 % more total storage root yield compared to sole sweetpotato. (P=0.0001). There was no significant increase in total storage root yield between 20 kg P ha ^{1} and 40 kg P ha^{-1} for sweetpotato- groundnut, sweetpotato-soybean intercropping and sole sweetpotato (P>0.05). Highest sweetpotato partial land equivalent ratio of 1.6 was attained on sweetpotato- groundnut intercropping at 20 kg P ha^{-1}. Total storage root yield increased by 33.6 % at 20 kg P ha^{-1} compared to 0 kg P ha^{-1}. Sweetpotato- groundnut intercropping had 48.3 % more commercial root yield compared to sole sweetpotato at 20 kg P ha-^{1} (P=0.036). Sweetpotato- groundnut intercropping at 20 kg P ha^{-1} had 27. 4 % more number of storage roots $plant^{-1}$ and higher harvest index compared to sole sweetpotato (P=0.001). Sweetpotato- soybean intercropping decreased number of storage roots $plant^{-1}$ compared to sole sweetpotato in 2014/15 growing seasons (P=0.008). There was no significant difference in the number of storage roots $plant^{-1}$ between sweetpotato- groundnut intercropping and sole sweetpotato cropping system (P>0.05). Sole sweetpotato at 20 kg P ha^{-1} had higher storage root diameter compared to sweetpotato-soybean intercropping (P=0.049). Sweetpotato- soybean intercropping had higher storage root length at 20 kg P ha^{-1} compared to 0 kg P ha^{-1} in 2013/14 and 2015/16 growing seasons (P=0.027). Total biomass at 20 kg ha^{-1}

was higher than at 0 kg ha^{-1} in all treatments (P=0.0001). Sweetpotato- groundnut, sweetpotato-groundnut- soybean intercropping and sole groundnut had a significantly higher pod yield at 20 kg P ha^{-1} than at 0 kg P ha^{-1} (P=0.005). Groundnut-soybean intercropping had a significantly lower shelled groundnut yield than sweetpotato-groundnut at 20 kg P ha^{-1} (P=0.017). Percent dry matter content was higher in sole sweetpotato at 40 kg P ha^{-1} compared to any other treatments involving soybean. Sweetpotato- groundnut and sole sweetpotato at 20 and 40 kg P ha^{-1} had more percent glucose content in 2014/15 and 2015/16 compared to the 2013/14 growing seasons (P<0.05). Percent starch content at 40 kg P ha^{-1} was higher than at 0 kg P ha^{-1} in all growing seasons (P=0.0001). There was a significantly higher β-carotene content in the storage roots in 2015/16 than 2013/14 growing seasons. Sweetpotato- groundnut intercropping at 0 kg P ha^{-1} had a higher iron (Fe) content in the sweetpotato storage roots compared to any other treatment (P=0.000). Sweetpotato –legume intercropping had more zinc (Zn) content in the storage roots and Zn yield in sweetpotato in 2015/16 compared to 2013/14 growing seasons (P=0.033). Farmers with the same environmentl conditions as where this study was carried out are recommended to intercrop sweetpotato and groundnut at 20 kg P ha^{-1}.

Key words: intercropping, legumes, micronutrient deficiency, nutritional quality, sweetpotato.

Opsomming

Patats (*Ipomoea Batatas* (L) Lam) is een van die belangrikste wortelgewasse in Mosambiek. Die opbrengs wat verkry word deur kleinskaalse boere is egter laer as die genetiese potensiaal as gevolg van swak grondvrugbaarheid en swak verbouiingspraktyke. Anorganiese bemestingstowwe wat moontlik kan bydra tot opbrengsverhogings is te duur en bemoeilik toegang daartoe. Een moontlikheid is om gebruik te maak van tussengewasverbouing met peulplantgewasse om grondvrugbaarheid te herstel en opbrengs te verhoog. In hierdie studie is die invloed van tussenverbouing van patat met sojabone en grondbone by drie fosfaatpeile (P) op grond se chemiese eienskappe, patat,grondbone en sojabone se vegetatiewe groei, opbrengs en voedingskwaliteit ondersoek.

Die studie is uitgevoer by die Umbeluzi navorsingstasie gedurende die 2013/14, 2014/15 en 2015/16 groeiseisoene. ‘n Faktoriaal eksperiment gereël as ‘n gesplete perseel uitleg is in hierdie studie gebruik. Die hoofperseelbehandelings vir die studie op grondchemiese eienskappe was sewe gewaskombinasies naamlik suiwer patat, suiwer grondboon, suiwersojaboon, patat-grondboon, patat-sojaboon, patat-grondboon-sojaboon en grondboon-sojaboon tussenverbouing. Die subperseelbehandelings was 0, 20 en 40 kg P ha^{-1} wat toegedien is met plant. Patat-grondboon, patat-sojaboon en sojaboon-grondboon tussenverbouing by 40 kg P ha^{-1} in die 2015/16 groeiseisoen het die totale grondstikstof (N) verhoog vergeleke met suiwer patat (P=0.038). Sojaboon-grondboon tussenverbouing teen 40 kg P ha^{-1} het minerale N inhoud van die grond betekenisvol verhoog vegeleke met die suiwer patat persele (P=0.01). Sojaboon-grondboon tussenverbouing teen 0 kg P ha^{-1} in die 2013/14 seisoen het meer Olsen P gehad as by dieselfde P vlak in al die groeiseisoene (P=0.023). Patat-grondboon en patat-sojaboon kombinasies by 40 kg P ha^{-1} het katioon uitruil vermoë (KUV) met 42.9% en 32.9% respektiewelik verhoog vergeleke met suiwer patat. Alle behandelings met peulgewasse in die mengsel het grond pH in 2014/15 en 2015/16 seisoene verlaag

vergeleke met die 2013/14 seisoen. Sojaboon-grondboon tussenverbouing, suiwer grondboon en suiwer sojaboon het hoër grondbeskikbare kalium (K) in die grond gelaat na oes as suiwer patat in 2013/14 (P=0.001). Patat-sojaboon tussenverbouing teen 20 kg P ha^{-1} het hoofstamlengte van patats betekenisvol verhoog vergeleke met suiwer patat. Daar was nie betekenisvolle verskille in patatstamlengtes tussen 20 en 40 kg P ha^{-1} in die tussenverbouingsbehandelings nie (P<0.05). Patat-grondboon tussenverbouing by 40 kg P ha^{-1} het vars wortelmassa plant^{-1} verhoog vergeleke met suiwer patat in die 2013/14 en 2014/15 groeiseisoene. Patat-grondboon-sojaboon, patat-sojaboon en patat-grondboon tussenverbouing by 0 en 40 kg P ha^{-1} het die aantal blare plant^{-1} verhoog vergeleke met suiwer patat. Suiwer patat het egter 'n groter stamdeursneë gehad vergeleke met patat-sojaboon tussenverbouing in beide die 2013/14 en 2014/15 groeiseisoene. Patat-grondboon tussenverbouing by 0 en 20 kg P ha^{-1} het totale stoorwortelmassa betekenisvol met 32.7% en 58.5% onderskeidelik verhoog vergeleke met suiwer patat by dieselfde P vlakke (P=0.0001). Daar was geen betekenisvolle toename in totale stoorwortelmassa tussen 20 en 40 kg P ha^{-1} in patat-grondboon, pata-sojaboon tussenverbouingstelsels en suiwer patat stelsels nie (P>0.05). Die hoogste patat gedeeltelike ekwivalent land verhouding (LER) was 1.6 vir patat-grondboon tussenverbouing by 20 kg P ha^{-1}. Totale stoorwortelmassa het met 33.6% vermeerder by 20 kg P ha^{-1} vergeleke met 0 kg P ha^{-1}. Patat-grondboon tussenverbouing het kommersiële wortelproduksie met 48.3% verhoog vergeleke met suiwer patat stelsels (P=0.036). Patat-grondboon tussenverbouing by 20 kg P ha^{-1} het die aantal stoorwortels plant^{-1} met 27.4% verhoog asook die oesindeks verhoog vergeleke met suiwer patat stelsels (P=0.0001). Patat-sojaboon tussenverbouing het die aantal stoorwortels plant^{-1} verminder vergeleke met suiwer patat in die 2014/15 groeiseisoen (P=0.008). Daar was geen betekenisvolle verskille tussen die aantal stoorwortels plant^{-1} in patat-sojaboon tussenverbouing en suiwer patat verbouingstelsels nie (P>0.05). Suiwer patat stelsels by 20 kg ha^{-1} het die stoorwortel deursneë verhoog

vergeleke met patat-sojaboon tussenverbouing (P=0.049). Patat-sojaboon tussenverbouing het stoorwortellengte verhoog by 20 kg P ha^{-1} vergeleke by 0 kg P ha^{-1} in die 2013/14 en 2014/15 groeiseisoene (P=0.027). Totale biomassa by 20 kg P ha^{-1} was betekenisvol hoër as by 0 kg P ha^{-1} by alle verbouingsbehandelings (P=0.0001). Patat-grondboon, patat-grondboon-sojaboon tussenverbouing en suiwer grondboon het betekenisvol meer peule gelewer by 20 kg P ha^{-1} as by 0 kg P ha^{-1} (P=0.005). Grondboon-sojaboon tussenverbouing het 'n betekenisvolle laer gedopte grondboon opbrengs gelewer as patat-grondboon tussenverbouing by 20 kg P ha^{-1} (P=0.017). Persentasie droëmateriaalinhoud van patatwortels het verhoog in suiwer patat stelsels by 40 kg P ha^{-1} vergeleke met enige ander behandeling wat sojabone ingesluit het. Patat-grondboon en suiwer patat stelsels het 'n hoër persentasie glukose inhoud in patatwortels tot gevolg gehad by 20 en 40 kg P ha^{-1} in die 2014/15 en 2015/16 groeiseisoene vergeleke met die 2013/14 groeiseisoen (P<0.05). Persentasie styselinhoud by 40 kg P ha^{-1} was hoër as by 0 kg P ha^{-1} in al die groeiseisoene (P=0.0001). Daar was 'n betekenisvolle hoër β-karoteen inhoud in die stoorwortels in 2015/16 as in die 2013/14 seisoen. Patat-grondboon tussenverbouing by 0 kg P ha^{-1} het meer yster (Fe) in die patat stoorwortels opgelewer vergeleke met enige ander behandeling(P=0.0001). Patat-peulplant tussenverbouing het 'n hoër sink (Zn) inhoud van stoorwortels en Zn opbrengs in patat in die 2015/16 seisoen tot gevolg gehad as in die 2013/14 groeiseisoene (P=0.033). Boere wat boer in dieselfde omgewingstoestande as waar hierdie studie uitgevoer is word aangeraai om tussenverbouiing met patat en grondbone uit te voer met toediening van 20 kg P ha^{-1}.

Sleutelwoorde: mikro-element tekorte, patat, peulplante, tussenverbouing, voedingskwaliteit

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Chapter 1

1. 1 General Introduction

Sweetpotato (*Ipomoea batatas* (L) Lam) belongs to the botanical family *Convolvulaceae* (morning glory family) and it is a perennial crop that is usually grown annually (Ukom et al. 2011). On the African continent it is predominantly grown as a food crop (Adebola et al. 2013). In Mozambique, sweetpotato production ranks third after cassava and maize among the food crops (FAOSTAT 2012). One key adaptation attribute making sweetpotato widely grown in Mozambique and other countries, is its ability to grow in poor marginal lands characterized by poor soil fertility and low precipitation (Laurie et al. 2015).

In sub-Saharan Africa, the white fleshed cultivars are predominantly grown due to their high dry matter content (Andrade et al. 2016). However, genetic diversity in sweetpotato is high with flesh colours ranging from white, orange, purple and cream; and growth habits range from erect, semi-erect and spreading (Aywa et al. 2013). However, among the sweet potatoes, the orange-fleshed sweetpotatoes (OFSP) contain beta-carotene, a pre-cursor to vitamin A. Malnutrition, largely due to vitamin A deficiency (VAD) is rampant in developing countries, the majority which are found in sub-Saharan Africa. Mozambique has the highest prevalence of vitamin A deficiency in southern Africa especially among children under the age of 5 (Low et al. 2007). Vitamin A deficiency causes increased infection rates from other diseases such as diarrhoea and causes a rise in night blindness. Globally, an estimated three million children go blind annually due to VAD and about two-thirds of these children die within months of going blind (Low et al. 2007). Development and health agencies have reacted to this crisis by distributing vitamin A capsules and fortifying processed and packaged foods. The results have been impressive (Tumwengamire et al. 2004). More than 12 million children received vitamin A supplements in 1997, and the total number of children suffering from blindness related to severe vitamin A deficiency was reported to have dropped significantly (Tumwengamire et al. 2004). Nevertheless, many families, particularly in rural areas, do not have access to capsules or costly fortified foods. In these areas therefore, vitamin A chronic deficiency is rife. One of the options to fight VAD especially in rural areas where approximately 70 % of the population reside in Mozambique is through agricultural based approaches using biofortified crops (Low et al. 2000, Forsman, 2014). During the past decade an increased effort to fight VAD saw the introduction of orange-fleshed sweetpotato (OFSP) cultivars in Africa. Mozambique was one of the pilot countries to adopt these cultivars where about 70 % of the children between 0 and 59 months are vitamin A deficient and 44 % of the population malnourished (GoM 2008). Estimates of 100 to 125 g of boiled or steamed OFSP meet the daily recommended intake levels of vitamin A for children under the age of five years (Low et al. 2009).

The average productivity of sweetpotato was 7.3 t ha^{-1} in 2013 in Mozambique (Andrade et al. 2016), one third of its potential. Reasons for low yield include drought; climate change, poor soil fertility, poor agronomic practises and high cost of external inputs such as inorganic fertilisers. Mozambican farmers have grown sweetpotato for many years as a sole crop in marginal areas with no fertilizer or other soil amelioration program (Andrade and Ricardo 1999). Yield potential of released sweetpotato cultivars is not realised because poverty stricken farmers do not have the resources to purchase fertilizers or reduce negative impacts of soil degradation. The few farmers who can afford fertilizers do not use it correctly in sweetpotato production systems as there is no documented fertilizer recommendation in Mozambique for this crop.

In order, to fight VAD efficiently there is need to produce a lot of vitamin A rich food from a unit area to meet the needs of rapidly increasing global population, which is growth projected to reach nearly 9 billion by 2050 (Tilman et al. 2011). The expected increase in food production will need to take place with less land available $capita^{-1}$ combined with strong negative effects of climate change. Under these circumstances, increasing agricultural productivity through intensification requires high levels of external inputs (Evans 1998). Agricultural intensification also produces side effects, such as soil erosion, environmental pollution by agrochemicals including greenhouse gas emissions, fertilizer misuse, and the appearance of weed and pest populations resistant to agrochemicals (Vandermeer 1998). Diversification of cropping systems by increasing the number of crop species grown in an intercropping system has been proposed as a solution to improve modern agriculture resulting in high and stable yields especially in poor countries like Mozambique (Poodineh et al. 2014). Cereal-legume intercropping is commonly employed in China and sub-Saharan Africa and has shown yield improvements and nutrient acquisition advantages (Wang et al. 2014). Intercropping associations vary from grain legumes with sweetpotato (Ossom et al. 2005), grain legumes with cassava (*Manihot esculenta* Cranz), yams (*Dioscorea* spp), sugarcane (*Saccharum officinarum L)*, maize (*Zea mays*) and other cereal crops (Ibeawuchi et al. 2005).

One characteristic of sweetpotato is its ability to grow in intercrops or as a relay crop. The sweetpotato crop can benefit from residual nitrogen (N) from legumes. Intercropping of sweetpotato and soybean (*Glycine max* (L.) as well as groundnut (*Arachis hypogaea L*) could be an appropriate cropping strategy to enhance crop yield and nutritional quality, improve soil nutritional quality by N fixation, increase ground cover thereby reducing weed competition, suppress soil erosion and reduce evapotranspiration (Poodineh et al. 2014).

There are few published studies available on intercropping legumes and sweetpotatoes at different phosphorus (P) rates on productivity, vegetative growth, sweetpotato storage root nutritional qualities and soil chemical properties. Agronomic studies to determine the effect P fertilizers as well as intercropping OFSP with legume crops (soybean and groundnut) on OFSP root yield and root nutrient qualities can provide recommendations to farmers in different agro-ecological zones of Mozambique to increase productivity.

1. 2 Rationale of the study

Most studies on intercropping in Mozambique have evaluated maize-sunflower (Lopez et al. 2001), maize-legume (Rusinamhodzi et al. 2012) and the results showed improved yield and nutrient acquisition The effects of sweetpotato–legume intercropping and the influence of P fertilization under rural farming systems has not been studied adequately in Mozambique. Studies by Zingore et al. (2007) with maize and beans suggest that the application of fertilizers and intercropping offers opportunities to improve overall productivity of both crops, thanks to increased availability of nitrogen and other macronutrients in the soil.

1. 3 Objectives

The objectives of the current study are:

(a) To evaluate soil fertility impacts resulting from OFSP-legume intercropping at different P application rates.

(b) To assess the effects of intercropping OFSP with groundnut and soybean at different P application, on vegetative growth of OFSP variety, groundnut and soybean crops.

(c) To assess the effects of intercropping OFSP with groundnut and soybean at different P application, on productivity of sweetpotato, groundnut and soybean crops.

(d) To assess the effects of intercropping OFSP with groundnut and soybean at different P application, on nutritional quality of orange-fleshed sweetpotatoes storage roots.

1. 4 Hypotheses

1. Soil chemical characteristics will not be improved by intercropping legumes and sweetpotatoes at different P application rates.

2. Intercropping OFSP with legume species at different P application rates will not increase the vegetative growth of sweetpotato, groundnut and soybean crops.

3. Intercropping OFSP with legume species will not increase yield and yield components of sweetpotato, groundnut and soybean.
4. Intercropping OFSP with groundnut and soybean at different P application, will not improve nutritional quality of OFSP storage roots.

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Chapter 2 : Literature review

2. 1 Origin and genetic diversity of sweetpotato

Sweetpotato (*Ipomoea batatas (L).* Lam*)* originated from Central America (Peet 2000; Zhang and Corke 2001). It is a dicotyledonous plant and a member of the *Convolvulaceae* family (John 2011). Eleven species in the section *batatas* are recognised including sweetpotato *(*Yen 1974) from the 900 different species in the *Convolvulaceae* family around the world (Yen, 1974). Sweetpotato is hexaploid (2n = 6x = 90) and self-incompatible although there are a few that are self- compatible sweetpotato varieties (YoungSup et al 2005).

Genetic diversity in sweetpotato is based on skin and flesh colours. The skin colours of sweetpotato range from white, cream, yellow, orange, pink, red to purple (Aywa et al. 2013) while flesh colours may be white or various shade of cream, yellow, orange or even purple (Aywa et al. 2013). Figure 2.1 represent the genetic diversity in sweetpotato germplasm. The orange fleshed sweetpotato are endowed with β- carotene, a precursor for vitamin A.

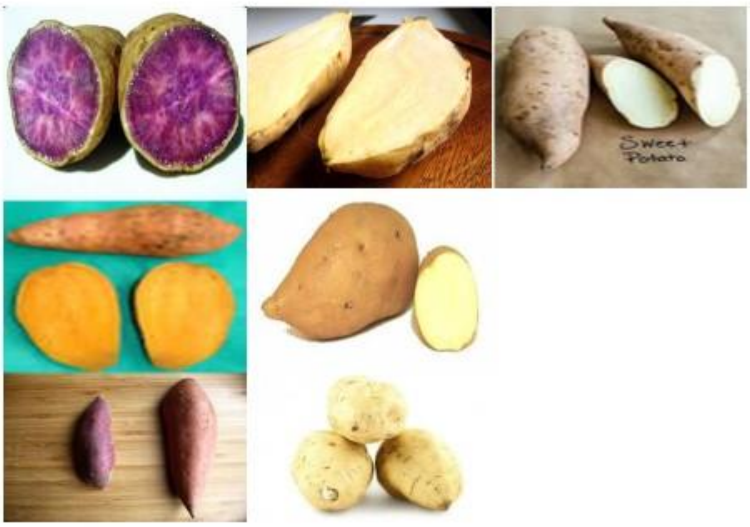

Figure 2.1. Genetic diversity of flesh and skin colours in sweetpotato

(North Carolina sweetpotato commission- http://www.ncsweetpotatoes.com/sweet-potatoes-101/sweet-potato-varieties/)

2. 2 Economic importance of sweetpotato in the world

Sweetpotato world production has been estimated at 110 million tons year^{-1} from more than 100 countries (Andrade et al. 2016b). Asia is the largest producer with 92.5 million tons year^{-1} and China alone contributes 85.2 million tons year^{-1} to this quantity (Andrade et al. 2016a). In Asia more than half of the production is used for animal feed (Woolfe 1992). Sweetpotato currently ranks as the fifth most important food crop on a fresh weight basis in developing countries after rice, wheat, maize and cassava. Sub-Saharan Africa produced 13.7 million tons year^{-1} mainly for human consumption. Mozambique is considered one of the highest sweetpotato producers in Southern Africa, and 780 000 metric tons were produced in 2008 alone (Andrade et al. 2010). Average yields have been estimated at 7.3 t ha^{-1} (Andrade et al. 2016b).

Sweetpotato is mainly cultivated by women for family consumption and cash income in sub Saharan Africa (Woolfe 1992). Sweetpotato provides a continuous supply of food or fodder throughout the year in marginal areas ensuring food security (Bourke 1982). The crop is traditionally cultivated for food as a root crop (Ruiz et al. 1981). The roots are consumed in different ways based on location. In most parts of the tropics sweetpotato is consumed boiled, roasted, baked and fried (Collins 1984). Dehydrated sweetpotato is ground into flour, which is cooked for human consumption in Japan (Giang et al. 2004). The tender leaves are used as vegetables in Africa, Indonesia and the Philipines (Aywa et al. 2013).

Sweetpotato especially the orange fleshed type is highly nutritious (Andrade et al. 2016a). Various parts of the crop contain both organic and mineral nutrients including vitamins A and C, zinc (Zn), potassium (K), sodium (Na), manganese (Mn), calcium (Ca), magnesium (Mg) and iron (Fe) (Ingabire and Vasanthakaalam, 2011; Ukom et al. 2011; Hue et al. 2012). Storage roots and leaves of sweetpotato are an excellent source of carbohydrate, protein, iron, vitamins

A and C and fibre (Smart and Simmonds 1995). The fresh storage root contains 80 to 90 % carbohydrate (Dominguez 1992), 3.6 to 5.4 % crude protein, 0.72 to 1.27 % fat, 2.5 to 3.25 % fiber and 2.5 to 3.2 % ash on a dry matter basis (Andrade et al. 2010). In addition, the storage roots of sweetpotato serve to a limited extent as a raw material for industrial purposes such as starch source and for alcohol production in Japan where about 90 % of the starch produced from sweetpotato is used to manufacture starch syrup, glucose and isomerised glucose syrup (high fructose syrup), lactic acid beverages, bread, as well as other products in the food industry such as distilled spirits called *shochu* (Singh et al. 2004). In China the starch is used for making pasta (Singh et al. 2004) and for producing alcoholic beverages. Sweet potato starch is used for the manufacture of adhesives, textile, confectionary and bakery industries (Collins 1984).

The plant is also a valuable forage crop for ruminants and other livestock species (Giang et al. 2004). Sweetpotato vines have crude protein contents ranging from 16 to 29% on dry matter basis which is comparable to leguminous forages (Valenzuela et al. 2000). Feeding of the vines to cows as a supplement to a basal diet of other forage crops increases milk yield (Etela et al. 2008).

2. 3 Sweetpotato production environments

Sweetpotato is widely grown between latitudes 40^0 N to 40^0 S, and at altitudes as high as 2500 m at the equator (Belehu 2003). It is tolerant to a wide range of edaphic and climatic conditions and adapts well to areas that are marginally not suitable for other crops (Lebot 2009, Andrade 2016a).

The crop grows best where the average temperature is 24 ^{0}C (Kay 1973). Growth is severely retarded at temperatures below 10 ^{0}C. The crop is damaged by frost restricting its cultivation in the temperate regions to areas with a minimum frost-free period of 4 to 6 months (Belehu

2003). The crop does not favour cooler temperatures as yield declines with increasing altitude in tropics (Belehu 2003). Kay (1973) reported yields to be 5 to 6 times higher at 25/20 ^{0}C than at 15/13 ^{0}C (day/night), and higher at a soil temperature of 30 ^{o}C than 15 ^{0}C. Maturity is also delayed in high altitude areas (Negeve et al. 1992; Belehu 2003).

Sweetpotato does well with 750-1000 mm of annual rainfall. The timing and distribution of moisture supply as well as the amount of rainfall affect yields (Belehu 2003). The crop is intolerant to water deficit and water logging during storage root initiation (Belehu 2003). Sweetpotato grows best on sandy-loam soils and does poorly on clay soils. Good drainage is essential since the crop cannot withstand water logging. Soil with high bulk density or poor aeration tends to retard storage root formation and result in reduced yields (Belehu 2003). Wet soil conditions at harvest lead to an increase in storage root rot and adversely affect yields, storage life, nutritional and baking quality (Belehu 2003).

2. 4 Health benefits of OFSP

Vitamin A deficiency (VAD) is one of the leading forms of micronutrient malnutrition and is a serious wide spread nutritional and public health problem affecting most people in the developing countries including sub-Saharan Africa (SSA) (Low et al. 2009). Most countries in SSA region are categorized by the world health organization as having a public health challenge concerning clinical and sub-clinical VAD (Mason et al. 2001).

Vitamin A deficiency prevalence is estimated at 36 million people in SSA (Mason et al. 2001). It is responsible for a significant number of infant mortality (Bryce et al. 2003) and hinders human capital development (Bryce et al. 2003). It is also estimated that some 3 million children in SSA under the age of 5 years suffer partial or total blindness as a result of VAD (Tumwengamire 2004). Vitamin A deficiency also increases children’s risk to common illnesses, impairs growth, development, vision, and immune systems, and in severe cases results in blindness and death (Ruel 2001, Future harvest 2004). Two thirds of the children who do not meet their requirements for vitamin A die from increased vulnerability to infection. In women, vitamin A deficiency increases risk of dying during pregnancy, as well as giving birth to low weight children (Ruel 2001).

Depending on the variety, 100 g of OFSP can provide β- carotene quantities that are sufficient to yield the recommended daily vitamin A requirements (Table 1) which is 375 µg $100g^{-1}$ for infants and 450 µg $100g^{-1}$ for children of 4-6 years (Tumwengamire et al. 2004). Because the body cannot convert all the β- carotene, this translates to about 2400 µg of β-carotene, an amount easily supplied by 100 g of OFSP (Tumwengamire et al. 2004). Some of the OFSP varieties tested by the International Potato Centre (CIP) have yielded up to 8000 µg of β- carotene from 100 g of fresh weight (Tumwengamire et al. 2004).

Table 2.1. Mean vitamin A requirements and recommended safe intake at different age groups

Age group	**Mean requirements (µg retinol equivalent day^{-1})**	**Recommended safe intake (µg retinol equivalent day^{-1})**
0-6 months	180	375
7-12 Months	190	400
1-3 years	200	400
4-6 years	200	450
7 years	250	500
adolescents 10-18 years	330-400	600
Adults		
Females 19-65 years	270	500
Males 19-65 years	300	600
65+	300	600
Pregnant women	370	800
Lactating women	450	800

Source: Adapted from FAO, Rome (1988)

Two studies by Van Jaarsveld et al. (2005) and Low et al. (2007a) from South Africa and Mozambique respectively, have demonstrated that regular consumption of OFSP significantly increased vitamin A status of children. Van Jaarsveld et al. (2005) evaluated the impacts of the consumption of OFSP on primary school children and the results proved that the consumption of OFSP significantly improved the vitamin A status of children. The study by Low et al.

(2007a) in Mozambique showed that in a rural setting the serum retinol of young children consuming OFSP significantly improved (Low et al. 2007a). The OFSP also emerged as the least expensive source of vitamin A in local markets (Low et al. 2007a). Low et al. (2007b) further suggested that the inclusion of OFSP as part of the integrated agriculture and nutrition approach could potentially play a significant role in combating VAD in developing countries.

The International Potato Centre (CIP) and its partner organizations have therefore taken up the food-based options to combat VAD in the sub-Saharan Africa through promotion of OFSP (Tumwengamire et al. 2004). This is because the rural and urban poor cannot afford expensive vitamin A rich food, such as fish oils, liver, milk, eggs and butter that contain vitamin A in its true form (retinol), which can be used by the body directly. Fifteen OFSP cultivars were released and are widely grown in Mozambique (Andrade et al. 2010).

2. 5 Cropping systems

Sweetpotato is mostly cultivated as a sole crop in most African countries. However, some farming communities harness its short duration maturity to put it in relay cropping, inter-cropping and rotation with other crops (Ghosh 1991).

2. 5. 1 Rotations

Sweetpotato is grown in various rotation systems around the world. Crop rotation is the practice of growing different crops, on the same land, in sequential planting cycles ranging from 2 to 8 years. In Zanzibar and Sierra Leone, the rice crop has been found to do well after sweetpotato (Onwueme 1978). Some parts of Mozambique such as Sofala and Nampula provinces also rotate sweetpotato with rice. A major advantage of sweetpotato in rotation is its ability to reduce crop losses due to disease and insects as well as replacing essential nutrients back into the soil due to high biomass that can be incorporated back into the soil. In China the typical farming system involves a rotation of wheat, corn and sweetpotatoes (Li et al. 2008).

2. 5. 2 Legume-sweetpotato intercrops in Mozambique

2. 5. 2. 1 Soybean production in Mozambique

Soybean is among the crops with huge growth potential in Mozambique and is becoming a major cash crop for smallholder farmers. Nationwide soybean production in 2004 was estimated at 770-880 tons from an average yield of 450 kg ha $^{-1}$ (Estrada 2004). Production increased 10-fold to 8000 tons in 2010 with an average productivity of 850 kg ha $^{-1}$ (CLUSA 2010). Soybean production is expected to increase over the coming years due to the high demand driven by the domestic poultry and livestock industries, available regional market and attractive prices (Estrada 2004). The importance of soybean as a source of oil and protein, and its ability to grow symbiotically on low-N soils, point to its continued status as the most valuable grain legume in the world. With limited new land on which to expand, and emphasis on sustainable systems, increases in soybean production will come mostly from increased yield per unit area. Improvements in biological nitrogen fixation can help achieve increased soybean production and improve soil fertility status. Sanginga et al. (2003) reported that some soybean varieties biologically fix 44 to 103 kg N ha^{-1} annually. However, this biological nitrogen fixation (BNF) process is primarily controlled by four principal factors: effectiveness of rhizobia-host plant symbiosis, ability of the host plant to accumulate N, amount of available soil N and environmental constraints (Omondi et al. 2014). In some cases soybean-*Bradyrhizobium* symbiosis can fix up to 300 kg N ha^{-1} under good soil conditions (Keyser and Li 1992).

The soybean is a legume which is native to East Asia and is classed as an oilseed (Newkirk 2010). Soybeans have become a popular global choice for food consumption, animal rations and edible oils because they are high in protein and oil. Oil content in soybean ranges from 18 to 21 % and protein content ranges from 36 to 40 % (Newkirk 2010).

2.5.2.2 Groundnut production in Mozambique

In the 2008/2009 growing season Mozambique produced 0.11 million metric tons of groundnuts from a total of 279,000 ha^{-1} (USDA-FAS 2010). Groundnuts (*Arachis hypogea* L.) plays an important role both as food crop and as a cash crop for smallholder farmers in Mozambique. The crop is also important for biological nitrogen fixation. Studies have shown that groundnuts can fix between 40 and 60% of their nitrogen requirements (Herridge 2008). Groundnuts can fix as much as 116 kg N ha^{-1} (Herridge 2008). Groundnuts is an important component of rural diet (Muindi and Bernardo 2010). Groundnut seeds (raw, sundried and roasted) contain crude protein of 24.70, 21.80 and 18.40 %; crude fat of 46.10, 43.80 and 40.60 %; crude fibre of 2.83, 2.43 and 2.41 %; carbohydrate of 17.41, 27.19 and 36.11 %; respectively (Ayoola et al. 2012). Groundnut oil is an important cooking medium and the flour is used to enrich relishes. Groundnut is also a rich source of minerals (P, Ca, Mg and K) and Vitamins (E, K and B group) (Ayoola et al. 2012).

A number of production constraints confront Mozambique farmers, such as cultivation of the crop on marginal lands under rain -fed conditions, occurrence of frequent drought stress due to vagaries of weather, a higher incidence of disease and pest attacks, low input-use, and factors related to socio-economic infrastructure. Mozambique is the largest producer of groundnut in southern Africa with 950 000 ha cultivated in 1996 (Subrahmanyam et al. 1999). Nampula province is the largest producer of groundnut in the country, although it is grown throughout the country, with the highest concentration in the northern region. Current average yield is very low, with a mean of about 200 kg ha^{-1} (Subrahmanyam et al.1999). Production constraints include non-availability of varieties adapted to various agro ecological zones and production systems, poor soil fertility and cultural practices, pests and diseases. Groundnut is grown as a mixed crop with pearl millet, *Phaseolus* bean, pigeon pea, sweetpotato, cowpea, maize, sorghum, cassava and with vegetables such as cucumber (Rao and Willey, 1980).

2. 5. 3 Legume-Sweetpotato intercropping

A decline in soil fertility across sub-Saharan Africa is evident and characterized mainly by nutrient mining and soil degradation (Hilhorst and Muchena 2000). One of the means of improving soil fertility management is through intercropping root crops with legumes (Ibeawuchi 2007).

Intercropping is the growing of two or more crops in proximity to promote interaction between them (Ibeawuchi 2007). Egbe and Idoko (2009) explained that intercropping is the growing of two or more crops simultaneously on the same field such that the period of overlap is long enough to include their vegetative stage. Population pressure has led to an intensification of intercropping in order to increase the production unit^{-1} area (Egbe and Idoko 2009). Intercropping sweetpotato with legumes will not only ensure better environmental resource utilization, but should also provide better yield stability, reduce pests and diseases and diversify rural income (Njoku et al. 2007). Some yield advantages have been derived from sweetpotato intercropping with okra (Njoku et al. 2007) and sweetpotato intercropped with pigeon pea (Egbe and Idoko 2009).

The use of legumes in mixed cropping systems is one of the traditional soil-fertility maintenance strategies (Shoko et al. 2009). The most common production systems of integrating legumes into cropping systems include the following: simultaneous intercropping, relay intercropping, rotations and improved fallows (Weber 1996). The use of legumes in cropping systems offers considerable benefits because of their ability to ameliorate soil fertility decline through fixation of atmospheric N and improve the yield of the subsequent crops (Giller et al. 1997; Shoko et al. 2009).

Legumes in an intercrop system also provide humus in the soil, due to decaying crop remains resulting in improved soil physical and chemical properties (Shoko et al. 2007). Water losses, soil erosion and leaching of nutrients are also reduced in intercropping systems due to the improved structure and better soil cover (Shoko et al. 2007). Fertilizers are more efficiently used in an intercropping system, due to the increased amount of humus and the different rooting systems of the crops as well as differences in the amount of nutrients taken up (Trenbath 1979). Shoko and Tagwira (2005) noted that legumes have the potential to improve soil pH and the availability of organic matter (OM), exchangeable bases and some trace elements such as Zn, Fe and Cu. Nutrient benefits of these systems may accrue more to subsequent crops after root and nodule senescence and decomposition of fallen leaves (Ledgard and Giller 1995).

2. 6 Advantages and disadvantages of intercropping:

The advantages of intercropping are risk minimization, effective use of available resources, balanced plant nutrition, increased crop productivity, erosion control, weed control, food security and efficient use of labour (Owuor et al. 2002). However, the efficient use of basic resources in the cropping system depends partly on the inherent efficiency of the individual crops that make up the system and partly on the complementary effect between the crops (Willey and Reddy 1981). There is reduction of insect/mite pest populations due to the diversity of crops grown and reduction of plant diseases because the distance between plants of the same species is increased. One crop can provide a barrier to the spread of a pest or disease of the other crop (Willey and Reddy 1981). Seran and Brintha (2010) noted that bud worm infestation in sole maize was greater than in maize intercropped with soybean. Soybean and groundnut are more effective in suppressing termite attack than common beans (Sekamatte et al. 2003).

One of the most important reasons to grow two or more crops together is to increase productivity per unit of land. The Land Equivalent Ratio (LER) is used to evaluate the effectiveness of intercropping systems (Mazaheri et al. 2006). Land equivalent ratio is the relative land area under sole crops required to produce equivalent yields achieved in intercropping systems (Njoku et al. 2007). The LER measure the yield advantage obtained by growing two or more crops or varieties as an intercrop compared to growing the same crops or varieties as a collection of separate monocultures (Mazaheri et al. 2006). It is the most widely used index for measuring the advantages of intercropping systems on combined yield of both crops (Mandal and Roy 1986). The LER is calculated using the formula

$$\mathrm{LER} = L_A + L_B = \frac{Y_A}{S_A} + \frac{Y_B}{S_B}$$

Where L_A and L_B are partial land equivalent ratios of component crops, Y_A is the yield of crop A under intercropping and S_A is the yield of sole crop A, Y_B is the yield crop B intercropped and S_B was the yield of sole crop B.

A LER value of 1.0, indicates no difference in yield between the intercrop and the collection of monocultures (Mazaheri and Oveysi 2004). Values greater than 1.0 indicate a yield advantage of the intercrop and show the presence of positive interferences among the variety or crop components of the mixture. That means any negative interspecific interference that exists in the mixture is not as intensive as the intraspecific interference that exists in the monocultures (Mazaheri et al. 2006).

There are few disadvantages that are associated with intercropping. Competition for water, light and nutrients may result in lower yields depending on the crops intercropped (Roger and Dennis, 1993). Other problems are difficulties in mechanization and hence increased human labour requirements (Roger and Dennis 1993).

2. 6. 1 Replenishment of soil fertility

Monoculture depletes soil fertility and destroys soil physical, chemical and biological properties leading to poor agricultural productivity (Vanlauwe and Giller 2006). Previous methods of soil fertility restoration such as shifting cultivation are no longer viable due to population increases and other factors (Ajayi et al. 2007). The rates of soil depletion in sub-Saharan Africa are estimated in the region of 22 kg ha^{-1} yr^{-1} for N, 2.5 kg ha^{-1} yr^{-1} for P, and 15 kg ha^{-1} yr^{-1} for K (Muchena et al. 2005). The losses can be as high as 112 kg N ha^{-1} yr^{-1}, 3 kg P ha^{-1} $yr^{-1}$and 70 kg K ha^{-1} yr^{-1} in intensively cultivated lands (Muchena et al. 2005). In addition, the organic matter content of the soils is declining as well (Ajayi et al. 2007). The losses in soil nutrition are higher than the estimated inorganic fertilizer use in Africa (Heisey and Mwangi 1996) and the overall result is nutrient mining over time.

Intensive crop production in many soils of sub-Saharan Africa requires high nutrient inputs because the soils are either derived from parent material with low levels of essential nutrients like P or the nutrients have been depleted of available nutrients through continuous cropping with insufficient fertilizer inputs (Sanchez et al. 1997). The low native soil P, high P fixation by soils with high Fe and Al concentration and nutrient depleting effects of long-term cropping without additions of adequate external inputs have contributed to P deficiencies in many tropical soils (Tisdale et al. 1999). Phosphorus can be replenished either immediately with high, one-time P application in soils with high P-sorption capacity, or gradually with moderate seasonal applications at rates sufficient to increase P availability in soils with low to moderate P-sorption capacity (Nziguheba et al. 1998).

The combination of P and N replenishment may have a synergistic effect. The elimination of P deficiency can also enhance N_2 fixation in legume crops (Giller et al. 1997). Application of organic material such as legume residues improves P levels directly by the process of decomposition and release of P from the biomass or indirectly by the production of organic acids (products of decomposition) that chelate Fe or Al, thus reducing P fixation (Nziguheba et al. 1998).

Although inorganic fertilizers are the most effective amendments to maintain soil fertility or alleviate nutrient deficiencies, their cost, inaccessibility and strict recommendations limit their use, particularly by smallholder farmers in SSA (Shoko et al. 2007). Continuous use of fertilizer alone cannot sustain crop yield and maintain soil fertility in the long-term because of soil acidification and loss of soil organic matter (Shoko et al. 2007). This therefore suggest that there is need for alternative cropping systems to suit the challenges of smallholder farmers in SSA.

2. 6. 2 Biological nitrogen fixation in legume-based intercropping system

Biological nitrogen fixation (BNF) enables legume crops to utilize atmospheric N. Biological nitrogen fixation is important in legume-based cropping systems especially where inorganic N is limited (Giller et al. 1997) or when mineral-N fertilization is neither available nor affordable to smallholder farmers (Giller et al. 1997). In addition, the soil may be replenished with N through decomposition of legume residues (Shoko et al. 2007). Some legume species commonly used for provision of grain and green manure have the potential to fix between 100 and 300 kg N ha $^{-1}$ from the atmosphere (Shoko et al. 2007). Legumes with capacity to fix large quantities of nitrogen into the soil include soybean, groundnuts and other tree species such as *cajunus cajan* (Giller et al. 1997).

2. 6. 3 Water use efficiency (WUE)

The availability of water is one of the most important factors determining productivity in intercropping systems. Improvement of water use efficiency in these systems lead to increases in the uses of other resources (Hook and Gascho 1988). Increased water use efficiency in sweetpotato-legume intercropping systems has been ascribed to water conservation largely because of early high leaf area index development and higher leaf area levels of sweetpotato (Ogindo and Walker 2005). Garba and Renard (1991) reported that a continuous pearl millet/forage legume system was the most efficient in terms of production and water use efficiency. Intercrops generally have better water use efficiency than sole crops (Ibeawuchi 2007). This is of special importance for farmers in the semi-arid tropics where water is the main limiting factor of production.

2. 6. 4 Nutrient use efficiency (NUE)

Increased nutrient uptake in intercropping systems can occur spatially and temporally. Spatial nutrient uptake can be increased through the increasing root mass, while temporal advantages in nutrient uptake occur when crops in an intercropping system have peak nutrient demands at different times (Anders et al. 1996). Furthermore, if the species have different rooting and uptake patterns, such as cereal-legume intercropping systems, more efficient use of available nutrients may occur and higher N-uptake in the intercrop have been reported, compared to monocrops (Fujita and Ofosu-Budu 1996). When only one species is grown, all roots tend to compete with each other since they are all similar in their orientation and below surface depth (Seran and Brintha 2010). Some studies have proven the comparative nutrient efficiency of intercrops to monocrops. For instance, Vesterager et al. (2008) found that maize and cowpea intercropping is beneficial on nitrogen poor soils. Chalka and Nepalia (2006) found that maize intercropped with soybean produced significantly lower NPK depletion and higher N uptake. Despite the beneficial effects of the intercropping to the cereal crops, it may also accelerate soil nutrient depletion, particularly for phosphorous, due to more efficient use of soil nutrients and higher removal through the harvested crops (Mucheru-Muna et al. 2010). Recent efforts on replenishment of soil fertility in Africa have been through the introduction of legumes as intercrop and/or in rotation to minimize external inputs (Seran and Brintha 2010).

2. 6. 5 Radiation use efficiency (RUE)

Total system light interception is determined by crop geometry and foliage architecture (Trenbath 1979a). If intercropping between high and low canopy crops is to improve light interception and hence yields of the shorter crops it requires that they be planted between sufficiently wider rows of the taller ones (Seran and Brintha 2010). Two factors that affect yield in relation to incident radiation in an intercropping system are the total amount of light intercepted and the efficiency with which intercepted light is converted to dry matter (Keating and Carberry 1993). Tsubo and Walker (2003) found that intercropped bean with maize had 77 % higher radiation use efficiency (RUE) than sole-cropped beans. Keating and Carberry (1993) found that maize–soybean intercropping has better use of solar radiation over the monocrops.

2. 6. 6 Weed control

Weed management is a key issue in organic farming systems (Bond and Grundy 2001). Improvement of crop competition with weeds has been emphasized as the benefit of the increased sowing density of sole crops or intercropping (Liebman and Davis 2000). Weed suppression has been found to be greater in intercrops compared with sole crops, indicating synergism among crops within intercrops (Liebman and Davis 2000). Intercropping grain crops can result in better resource utilization and there is a certain degree of weed suppression. Weed growth basically depends on the competitive ability of the whole crop community, which in intercropping largely depends on the competitive abilities of the component crops and their respective plant populations (Liebman and Davis 2000). Maize-bean intercropping reduced weed biomass by 50-66 % (Mashingaidze 2004).

2. 6. 7 Erosion control

Intercropping systems control soil erosion by preventing rain drops from hitting the bare soil where they tend to seal surface pores, prevent water from entering the soil and increase surface runoff (Seran and Brintha 2010). In maize- cowpea intercropping system, cowpeas act as best cover crop and reduced soil erosion compared to a maize- bean system (Kariaga 2004). Taller crops act as wind barrier for short crops, in intercrops of taller cereals with short legume crops (Reddy and Reddi 2007). Similarly, sorghum- cowpea intercropping reduce runoff by 20-30 % compared with a sorghum sole crop and by 45-55 % compared with cowpea monoculture (Kariaga 2004).

2. 6. 8 Yield Stability

Intercropping does not only enhance diversity of farm products but also provides insurance against crop failure (Ibeawuchi 2007). With diversified crops, intercropping stabilizes yield through the principle of compensation (Ibeawuchi 2007). When one crop component suffers from pests, diseases or drought the loss of this crop is compensated at least partially by the other component crop(s) since there is now less competition for growth resources. There would be no compensation if it were only a sole crop system (Ibeawuchi 2007).

2. 7 Sweetpotato production aspects

Sweetpotato is a crop that is very well suited to local growing conditions in Mozambique and can be grown in a wide range of soil conditions (Andrade and Ricardo 1999). A reasonable sweetpotato yield can be achieved in marginal areas where most crops can hardly be productive (Belehu 2003). However, production techniques are important for improved productivity. Sections 2.7.1 to 2.7.1.3 show detailed production aspects of sweetpotato.

2. 7. 1 Environmental conditions

Sweetpotato is grown in a wide range of environments. It grows from sea level to 2,700 m altitude, and occasionally up to 2,850 m. Sweetpotato is grown on a wide range of soil types in the highlands, with soil texture ranging from sandy loams to heavy clays, and in soils with a wide range in fertility (Kirchhof 2009). Sweetpotato has a moderate need for N and a low requirement for P, and is a high user of K. While N is required for adequate vegetative growth and good root yield, excessive N leads to vigorous vegetative growth at the expense of root formation and yield. The greatest nutritional requirement of the crop is for K (Kirchhof 2009).

2. 7. 2 Tillage and seedbed preparation

The purpose of land preparation is to improve the infiltration of water, the penetration of roots and, to incorporate plant residues into the soil (Belehu 2003). Root and tuber crops in general require a loose soil in which the tubers can grow with little hindrance. The reasons for this seem to lie in the manner in which the tuber form and penetrate the soil. Many tuber crops such as cassava and sweetpotato initially form relatively thin roots, which first penetrate the soil, and later enlarge to form the tuber (Belehu 2003). On the basis of the type of the land tillage, three general methods of sweetpotato planting exist. Planting on mounds, planting on ridges and planting on the flat land. The first method is representative of traditional peasant sweetpotato production methods, while the latter two are characteristics of partially mechanized and mechanized production systems.

2. 7. 2. 1 Mounding

Planting of sweetpotato on mounds is the most common practice in traditional agriculture in most parts of Africa (Belehu 2003). This planting system is also common in some parts of Mozambique. Essentially, the topsoil is gathered into more or less conical heaps at various points in the field. Hoes with wide blades are used for the mound making. The size of each mound, the mean distance between mounds, and the number of sweetpotato cuttings planted on each mound vary from place to place and depends on the size of each mound. In general, the bigger the mound the greater the distance between the mounds, and the greater the number of the cuttings that may be planted on each mound. According to Onwueme (1978) in some parts of south eastern Nigeria, mounds may attain heights of up to 1 m. The distances between the mounds can be as much as 3 m (Belehu 2003). In most sweetpotato growing areas of Africa smaller mounds of 50 cm in height are more common, and only 5 or 6 cuttings are planted on each mound (Chagonda et al. 2014). There are several advantages of high mounds; they provide a favourable seedbed for storage root development and in soils where the water table is high, mounds also serve to keep most of the roots above the water table thereby reducing rotting (Chagonda et al. 2014). Besides all its advantages mounding has the major disadvantage that it is an extremely tedious and labour consuming operation, which is very difficult to mechanize (Belehu 2003).

2. 7. 2. 2 Ridging

Planting on ridges is the most universally recommended method of growing sweetpotato (Belehu 2003; Chagonda et al. 2014). It has been shown that the higher the ridges, the greater the yield up to a ridge height of 40 cm (Chagonda et al. 2014). The optimum height of the ridge will depend on the soil type and the cultivar being grown (Belehu 2003). A high ridge provides ample depth of loose, fertile soil for root and storage root development and a high, broad ridge is less readily washed away by rain during the cropping season. After the ridges have been made, the actual planting of the cuttings on the ridge is done by opening up the soil at the crest of the ridge with a hoe (Parwada et al. 2011, Chagonda et al. 2014). Planting on ridges has several of the same advantages as planting on mounds. In addition, it has the added advantages that ridge making is completely mechanized, and that ridging along the contour can help in erosion control in sloping areas (Belehu 2003). The major disadvantage of ridge planting is that during the course of the season rains tend to wash soil away from the ridge-top, thereby decreasing the height of the ridges. The washing may progress to an extent where storage roots growing within the soil become exposed (Chagonda et al. 2014). Such exposed storage roots are generally unpalatable and are easily attacked by rodents and weevils (Chagonda et al. 2014).

2. 7. 2. 3 Flat Planting

In flat planting, ploughing and harrowing is done first. After that, the cuttings are planted in rows on the unridged land (Parwada et al. 2011). Planting on flat land have several of the same advantages as planting on ridges. Compared to the mound and ridge methods the top soil may be shallower in flat planting which may cause rotting of the storage roots during wet periods (Parwada et al. 2011).

2. 7. 3 Planting material

Sweetpotato can be propagated by means of sprouts from storage roots or by means of vine cuttings. Healthy storage roots of 20 to 50 g should be planted 3 cm deep (Belehu 2003, Parwada et al. 2011). Vine cuttings are the usual method of propagating sweetpotato (Parwada et al. 2011). Vine cuttings are better than using sprouts from storage roots for several reasons. Firstly, plants derived from vine cuttings are free from soil-borne diseases. Secondly, by propagating with vine cuttings, the entire storage roots harvest can be saved for consumption or marketing instead of reserving some of it for planting purposes. Thirdly, vine cuttings yield better than sprouts, and produce storage roots of more uniform size and shape (Belehu 2003). In the use of vine cuttings, apical cuttings are preferred to those from the middle and basal portion of the stem (Parwada et al. 2011).

However, where the planting material is in short supply, the middle portion of the vine cuttings can be used with little decrease in expected yield. Chagonda et al (2014) indicated that storage root yield tend to increase with increase in the length of the vine cuttings used, and a length of about 30 cm is recommended. Cuttings of greater length than this tend to be wasteful of planting material, while shorter cuttings establish more slowly, and give poorer yields. Various strategies can be adopted to ensure an adequate supply of planting material at planting time, including nurseries, sprouts from storage roots and successive planting.

The advantage of sprouts as a source of planting material is that the roots can be selected, stored in sand during the dry season and the farmer can stimulate sprouting at least 8 weeks before the rains start (Stanthers et al. 2013). This technology is called triple S (Sand, Storage and Sprouting). Triple S is a technology developed by the International Potato Centre. With this technology the farmer can store healthy sweetpotato storage roots for 3 to 4 months in sand and then stimulate sprouting by providing moisture so that enough planting material is available at the onset of the planting season (Stanthers et al. 2013).

2.7.3.1 Production of sprouts from storage roots

Sprouts from storage roots are the standard method of producing planting material for the sub-tropical and temperate regions (Belehu 2003, Parwada et al. 2011). The method involves growing storage roots in beds of soil or sand (Stanthers et al. 2013). Storage roots are spaced close together, covered shallowly with soil, and kept watered. Sprouts emerge after approximately two weeks and can be utilized for planting within few weeks after bedding. Sprouts can be pulled at weekly intervals (Belehu 2003). In order to maximize the production of sprouts, large storage roots can be cut transversely into two or three pieces, so as to minimize proximal dominance. The storage roots may also be treated with plant growth regulators, which have been reported to improve the production of sprouts. Such treatments include dipping in 12 % dimethyl sulphoxide (DMSO) for up to 20 minutes (Whatley 1969) before bedding. It is also advantageous to disinfect the storage roots before they are bedded.

2.7. 3. 2 Nursery plots

Nursery plots involves maintaining plots of sweetpotato during the non-growing season (Belehu 2003). For most part of the tropics where the non-growing season corresponds to the dry season, the nursery plots are often established on stream banks. Nursery plots are commonly established at the time of harvest to utilize vine cuttings from the previous crop (Belehu 2003). However, with the triple S system using sprouts the roots can be kept in sand and the nursery is established a few weeks before onset of rains.

2.7. 4 Planting, weeding and fertilization

2.7. 4. 1 Planting

Vine cuttings are generally planted vertically at an angle or horizontal to the surface with three to four nodes in the soil (Parwada et al. 2011). At planting, the vine is inserted into the soil so that one-half to two thirds of its length is beneath the soil surface. The placement of the vine or sprout is done by hand in most parts of the tropics, but single row or multiple row planters, which can plant cuttings, are available. Most of these planters have devices which water the plants or provide them with nutrient solutions as they are operating in the field. It is, therefore, possible even to plant during a dry spell in anticipation of the rains. The vines are normally planted 25 to 30 cm apart on ridges that are 60 to 90 cm apart (Onwueme 1978, Belehu 2003). Cultivars with trailing stems are planted wider apart than those with semi trailing stems. Sweetpotato is able to compensate to some extent for variation in planting density. As plant population per hectare increases the number of tubers per plant decreases, the mean weight per storage roots decreases, and the yield per plant decreases (Belehu 2003). It is best to plant sweetpotato early in the growing season so that the entire rainy season can be utilized. Where the rainy season is very long planting may be delayed and timed such that the crop matures as rainfall begins to decline (Belehu 2003).

2.7. 4. 2 Weed control

Weeds are a problem in sweetpotato only during the first two months of the growth. Sweetpotato vines grow quickly and may reach full canopy closure in about six weeks (Belehu 2003). Vigorous growth of the vines causes rapid and effective coverage of the ground surface and smothers the weeds (Poodineh et al. 2014). Harris (1958) reported that a crop of sweetpotato would practically eliminate an infestation of nutsedge *Cyprus rotundus*. For this reason, most traditional farmers do not bother to weed sweetpotato plots at all. Alternatively, a single hoe weeding is done about four weeks after planting (Poodineh et al. 2014).

2.7. 4. 3. Fertilizers

Sweetpotato is often considered as a crop associated with poor soils (Belehu 2003). This is probably because it is well suited to sandy soils that are often infertile, and because storage root yields are sometimes depressed in very fertile or heavily fertilized soils (Prabawardani and Suparno 2015). Nevertheless, good yields can be obtained only under conditions of high, but balanced, nutrition. As with most root crops, sweetpotato has a high requirement for potassium relative to nitrogen (Prabawardani and Suparno 2015). Sweetpotato small scale farmers in Mozambique generally would not apply fertilizers for two reasons. Firstly the response of sweetpotato cultivars to different fertilizers has not been clearly established. Secondly the crop is often not paying the cost of the fertilizers.

2.8 Conclusion

Due to an ever increasing human population, especially in Africa, leading to diminishing land sizes and soil fertility depletion, intercropping with its advantages of risk minimization, reduction of soil erosion, nitrogen fixation and increased food security could probably be a better option to deal with food insecurity and nutrition problems in SSA in general and in Mozambique in particular. Most crops can now be intercropped including fruit trees and therefore farmers with small pieces of land can make more productive use of their land.

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Chapter 3 : Influence of intercropping sweetpotato, groundnut and soybean on soil chemical properties

Abstract

Yield and nutrient recapitalisation advantages are frequently found in intercropping systems and incorporation of crop residues after harvesting. However, sweetpotato yield in Mozambique is lower than its potential due to soil fertility depletion and poor agronomic practices. The objective of the study was to investigate the influence of intercropping sweetpotato, groundnut, soybean at three phosphorus (P) levels and incorporation of crop residues after harvest on soil chemical properties. A study was conducted at Umbeluzi research station during the 2013/14, 2014/15 and 2015/16 growing seasons. The main plot treatments were sole sweetpotato, sole groundnut, sole soybean, sweetpotato- groundnut, sweetpotato-soybean, sweetpotato- groundnut- soybean and groundnut- soybean intercropping. Subplot treatments were 0, 20 and 40 kg P ha^{-1} applied at planting. Sweetpotato- groundnut, sweetpotato- soybean and groundnut- soybean intercropping at 40 kg P ha^{-1} in the 2015/16 growing season had more soil total nitrogen (N) compared to sole sweetpotato. Mineral N was 63.2 % higher in soybean- groundnut intercropping compared to plots with sole sweetpotato crop at 40 kg ha^{-1} (P=0.01). Sole sweetpotato at 40 kg P ha^{-1} had higher total P than all treatments in the 2013/14 growing season except in sweetpotato- groundnut- soybean intercropping (P=0.023). Groundnut- soybean intercropping at 0 kg P ha^{-1} in 2013/14 growing season had more Olsen P than sole sweetpotato (P=0.023). Sweetpotato- groundnut and sweetpotato- soybean intercrops at 40 kg P ha^{-1} had 21 % and 25.3 % respectively more CEC compared to sole sweetpotato. All treatments involving legumes in the mix reduced soil pH in 2014/15 and 2015/16 compared to the 2013/14 growing season. Sole sweetpotato had a 36.3 % and 61.7 % lower soil total K than sweetpotato- soybean and sweetpotato- groundnut-soybean intercropping respectively in the 2015/16 growing season (P=0.0001). Sole

groundnut had more available K in the soil compared to sweetpotato- soybean, sweetpotato-soybean- groundnut intercropping and sole sweetpotato at 0 kg P ha^{-1}. Soybean-groundnut intercropping, sole groundnut and sole soybean had higher soil available K than sole sweetpotato and any other intercropping combination involving sweetpotato in the mix in the 2015/16 growing season ($P<0.001$). It was recommended that intercropping sweetpotato with groundnut and soybean at 40 kg P ha^{-1} gave the best results for soil fertility improvement.

Key words: Crop residues, intercropping, soil fertility,

3.1 Introduction

The competition for land is becoming intense with the continuous rise in human population and thus resulting in the continuous use of land in the farming system (Tilman et al. 2011). Consequently, the traditional shifting cultivation that was used to ensure that crops obtain adequate soil nutrient supply to promote maximum yield have become unsustainable (Shoko et al. 2014). There are limited opportunities for building soil organic matter mainly because of monoculture production systems (Giller and Wilson 1991), rendering farmers to rely heavily on external nutrient inputs annually. Some options available to reduce this problem, include the application of organic and inorganic fertilizers.

However, use of inorganic fertilizers by most of the smallholder farmers in southern Africa has been very poor, because of cash limitations and poor access to fertilizer markets (Ahmed et al. 1996). Only a few farmers in Mozambique use inorganic fertilizers for the production of crops such as cereals, legumes and roots and tuber crops and in most cases they use sub-optimal amounts of inorganic fertilizers. This has resulted in poor yields and has aggravated the food insecurity situation (Shoko et al. 2014) in Mozambique. Materials for organic fertilizers are also difficult to acquire as farmers prefer supplying stover to livestock rather than leaving them in the field to decay and consequently release nutrients (Baijukya, 2005). In addition, the use of inorganic fertilizers have proved to be ineffective in restoring soil fertility because of associated problems such as eutrophication and pollution in rivers (Sullivan 2003).

Adoption of more sustainable strategies for the maintenance of soil fertility has become imperative to sustain crop yield. Intercropping with legumes can be used as an alternative nutrient input through biological nitrogen (N) fixation. Positive residual effects of N-fixing legumes on subsequent crop in intercropping systems have been widely reported in both old and modern agriculture (Shah and Khan 2003, Sanginga 2012). The beneficial effect on succeeding crops is usually attributed to the increased soil fertility because of nitrogen fixation by the previous leguminous crop. Although the nutrient content from intercropping are relatively lower than in inorganic fertilizers, they have the additional advantage of improving the physical properties of the soil after incorporation of crop residues (Abou El-Magd et al. 2006): Thus physical soil characteristics such as water infiltration rate, water holding capacity, and aeration, are generally improved (Stevenson 1994).

The biological characteristics of soil, such as rhizosphere exudates, micro flora/fauna, biological activity, and biodiversity, can also be improved through intercropping (Stevenson 1994, Abou El-Magd et al. 2006). Studies have shown that combined application of inorganic fertilizers and intercropping have resulted in significant increases in crop yield and increases in soil nutrients as compared with sole application of inorganic fertilizers (Mahmoud et al. 2009) and such combinations have also been found to be economically efficient (Jayathilake et al. 2006). Application of phosphorus (P) on legumes is effective in improving nodulation and hence nitrogen fixation (Ojo et al. 2016).

The aim of this study was to investigate the effects of sweetpotato-legume intercropping at three P levels on soil chemical properties.

3.2 Materials and methods

3.2.1 Experimental site

A field experiment was carried out at Umbeluzi research station (26° 03’ S and 32° 15 ‘E, 12 meters above sea level) (Andrade et al. 2016) 40 km from Maputo, Mozambique during the 2013/14, 2014/15 and 2015/16 growing seasons. Umbeluzi has a pronounced dry season from May to October and a wet season from November to March.

3.2.2 Meteorological data at the experimental site

Meteorological data show that mean temperatures declined in 2014/15 and went up again in the 2015/16 growing season while total rainfall declined gradually during the experimental period (Table 3.1).

Table 3.1. Meteorological data for Umbeluzi research station during the experimental period

Growing season	Month/year	Max T°C	Min T°C	Average T°C	Rainfall(mm)
2013/14	December 2013	28.6	20.2	24.4	231.3
	January 2014	31.7	22.1	26.9	111.3
	February 2014	33.0	21.9	27.5	113
	March 2014	30.7	21.0	25.9	140
	April 2014	29.8	16.8	23.3	136.4
	May 2014	20.6	14.3	17.5	166.4
	Mean	**29.1**	**19.4**	**24.3**	
	Total				**898.4**
2014/15	December 2014	29.8	20.7	25.3	504.1
	January 2015	31.8	21	26.4	61.9
	February 2015	31.6	21	26.3	150.4
	March 2015	32	20.8	26.4	10.8
	April 2015	29.3	22.1	25.7	45.2
	May 2015	29.3	16	22.7	44.6
	Mean	**25.3**	**16.8**	**21.1**	
	Total				**817.0**
2015/16	December 2015	30.3	13.2	21.8	219.9
	January 2016	27.9	20.2	24.1	153.6
	February 2016	28.3	22.2	25.3	116.6
	March 2016	29.1	19.8	24.5	138
	April 2016	27.7	19.5	23.6	122.3
	May 2016	27.2	15.9	21.6	62.7
	Mean	**28.4**	**18.5**	**23.5**	
					813.1

Source: Umbeluzi research station weather station

3.2.3 Site Characterisation at the start of the experiment at Umbeluzi research station.

At the start of the experiment within 0-20 cm depth, the soil chemical characteristics were pH 7.13, 0.025 % total nitrogen (N), 0.019 % mineral nitrogen (N), 220 mg kg^{-1} total phosphorus (P), 3.5 mg $100g^{-1}$ Oslen phosphorus (P), 2.9 meq $100g^{-1}$ total potassium (K), 0.64 meq $100g^{-1}$ available potassium (K) and 23.2 meq $100g^{-1}$ cation exchange capacity (CEC).

3.2.4 Experimental design

The experiment was laid out in a 7 x 3 factorial setup in a split plot in a randomized complete block design (RCBD) with three replications. Sweetpotato variety, Namanga was intercropped with groundnut variety Bebiano Vermelho and soybean variety Zamboane. The main-plot treatments were 7 crop combinations (i) sweetpotato sole crop, (ii) groundnut sole crop, (iii) soybean sole crop, (iv) intercropping two rows of groundnut between sweetpotato rows, (v) intercropping one row of soybean between sweetpotato rows (vi) intercropping two rows of groundnut between sweetpotato rows followed by a row of soybean between sweetpotato rows and (vii) intercropping two rows of groundnut between soybeans rows. The sub-plot treatments comprised of three P levels at 0, 20 and 40 kg ha^{-1}. Fertilizer (P) was applied at planting and the source of P was single superphosphate. Nitrogen and potassium (K) were applied uniformly across all treatments at 20 days after planting with 50 kg N ha^{-1} applied as urea and 150 kg K_2SO_4 ha^{-1} to avoid nutrient deficiencies. All the fertilizers were incorporated into the soil through localized placement using the half-circle method around the seed or vine cutting. Planting was done on 15 December 2013, 26 December 2014 and on 10 January 2016 in the first, second and third growing seasons respectively. Each main plot had an area of 90 m^2 and each subplot had an area of 30 m^2. Sweetpotato vine cuttings measuring 20 cm with four nodes were planted at the crest of ridges at 90 cm inter row spacing and 30 cm in row spacing (37037 sweetpotato plants ha^{-1}). Groundnut and soybean seeds were simultaneously planted in between sweetpotato ridges. Groundnut was planted at 25 cm in-row spacing with two groundnut rows planted between two sweetpotato ridges (88 888 groundnut plants ha^{-1}). One soybean row was planted between two sweetpotato ridges at a spacing of 5 cm within the row with one seed $hole^{-1}$ (222 222 soybean plants ha^{-1}). Soybean seeds were inoculated by *Bradyrhizobium japonicum* before planting.

Sweetpotato harvesting was done on 15 May 2014, 26 May 2015 and 10 June for the 2013/14, 2014/15 and 2015/16 growing seasons respectively. Groundnut was harvested on 30 March 2014, 10 April 2015 and 20 April for the 2013/14, 2014/15 and 2015/16 growing seasons respectively. Soybean was harvested on 9 April 2014, 20 April 2015 and 30 April for the 2013/14, 2014/15 and 2015/16 growing seasons respectively. One week after each harvest all crop residues were incorporated into the soil. The experiment was repeated in the same field over three growing g seasons (2013/14, 2014/15 and 2015/16).

3. 2. 5 Soil chemical properties measured

From each of the plots, soil samples were collected using an auger to a depth of 20 cm. Soil sampling was done at the end of each growing season just after harvesting. In each subplot, six replicate cores were collected from intercropping rows of sweetpotato and associated legume crops at random and mixed together to give one composite sample. A total of 63 composite samples were collected, packed and stored in khaki envelopes, air-dried and sieved through a 2.0 mm mesh. Plant residues and roots were removed by hand from the soil prior to chemical analysis.

Total N was determined by the modified Kjedahl method according to standard protocols (SKD-800, Shanghai, Peiou Corporation). Mineral N was determined by the colorimetric method. Total P was determined by the bray 1 extractable method. Soil Olsen P was determined using standard procedures (Olsen 1954) by colorimetry. Total K was determined by the aqua regia method. Soil available K was extracted using 1 mol L^{-1} ammonium acetate solution buffered at pH 7 described by Rayment and Higginson (1992) and determined by flame photometry. Cation exchange capacity (CEC) was determined by the Ammonium acetate method of Schollenberger and Dreibelbis (1930) which was buffered at pH 7. Soil pH was determined in soil suspension with deionized-distilled water in a 1:5 soil: water extract (Rayment and Higginson 1992). Soil sample analysed was carried out at the Eduardo Mondlane University soil laboratory in Maputo.

3.2.6 Data analysis

The data was subjected to analysis of variance (ANOVA) using statistica software version 13.0 and means were compared using the Fishers LSD test at 5 % probability.

3.3 Results

3.3.1 Significance of F values

Summary of ANOVA and F values for the measured parameters are shown in Table 3.2. Intercropping x P x season interaction significantly affected percent total N, total p and Olsen P (Table 3.2).

Table 3.2. Significant effects (F- values) done on analysis of variance on measured soil parameters at Umbeluzi research station in Mozambique in 2013/14, 2014/15 and 2015/16 growing seasons

Source of variation	pH (H_2O)	% Total N	% Mineral N	Total P(mg kg^{-1})	Olsen P (mg $100g^{-1}$)	CEC(meq $100g^{-1}$)	Total K (meq $100g^{-1}$)	Available K (meq $100g^{-1}$)
I	***	ns	ns	ns	*	*	*	ns
P	ns	ns	ns	ns	ns	***	*	ns
S	***	***	***	***	***	***	***	***
I x P	ns	*	*	ns	ns	***	ns	*
I x S	***	***	ns	ns	*	ns	***	***
P x S	***	ns	ns	ns	***	ns	ns	*
I x P x S	ns	*	ns	*	*	ns	ns	ns

*, *** Significant at P≤0.05, P≤0.001 respectively, ns denotes non significance at P≤0.05.
I-intercropping, P-phosphorus S- season, I x P-intercropping x Phosphorus, I x S-intercropping x season, I x P x S-intercropping x Phosphorus x season interaction.

Cation exchange capacity was significantly affected by intercropping x P interaction and the main effects of intercropping, P and seasons (Table 3.2).

3.3.2 Soil pH

There was no significant difference in soil pH between sole sweetpotato, sole groundnut, sweetpotato- groundnut, sweetpotato- soybean, soybean- groundnut, sweetpotato- soybean-groundnut intercropping in the 2013/14 growing season but sole sweetpotato had significantly higher soil pH than the other treatment combinations in the 2015/16 growing season (P=0.0001) (Table 3.3).

Table 3.3. Effect of intercropping sweetpotato, groundnut and soybean on soil pH during 2013/14. 2014/15 and 2015/16 growing season

Intercropping x seasons	**pH(H_2O)**			
	Growing seasons			
Intercropping	**2013/14**	**2014/15**	**2015/16**	**Mean**
Sole sweetpotato	7.15[ab]	6.51[efg]	7.16[ab]	**6.94**
Sole soybean	6.90[cd]	6.29[ij]	6.48[efg]	**6.56**
Sole groundnut	6.99[bc]	6.26[j]	6.44[efgh]	**6.56**
Sweetpotato- groundnut	7.11[b]	6.31[hij]	6.58[e]	**6.67**
Sweetpotato-soybean	7.26[a]	6.41[fghi]	6.55[ef]	**6.74**
Soybean- groundnut	7.08[b]	6.31[hij]	6.51[efg]	**6.63**
Sweetpotato- groundnut- soybean	7.05[b]	6.38[ghij]	6.82[d]	**6.75**
Mean	**7.07**	**6.35**	**6.65**	**6.69**
% CV	**2.3**			
Intercropping x season LSD $_{0.05}$	**0.14**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

There was a significantly higher soil pH in the 2013/14 growing season than in the 2014/15 and 2015/16 growing seasons for all treatments involving legumes in the mix (P=0.0001) (Table 3.3). Sweetpotato-groundnut, sweetpotato- soybean, soybean- groundnut, sweetpotato-soybean- groundnut intercropping resulted in a pH decline of 8.1 %, 10.8 %, 8.8 % and 3.4 % respectively from the 2013/14 to 2015/16 growing seasons (Table 3.3).

There was a significantly higher soil pH in the 2013/14 season than in the 2014/15 and 2015/16 growing seasons at all P levels (Table 3.4). Increasing P from 0 to 20 kg ha^{-1}

significantly increased soil pH by 1.7 % in the 2015/16 growing seasons (Table 3.4). There was no significant difference in soil pH between 20 and 40 kg P ha^{-1} in all the growing seasons (P>0.05) (Table 3.4). In the 2013/14 and 2014/15 growing seasons, there was no significant difference in soil pH between 0 kg P ha^{-1} and both 20 and 40 kg P ha^{-1} but in the 2015/16 growing season, P application at 20 and 40 kg ha^{-1} resulted in significantly higher soil pH than at 0 kg P ha^{-1} (P=0.005) (Table 3.4). Phosphorus x season interaction was significant for soil pH (P=0.005) (Table 3.3).

Table 3.4. Effect of P levels on soil pH over three growing seasons at Umbeluzi research station

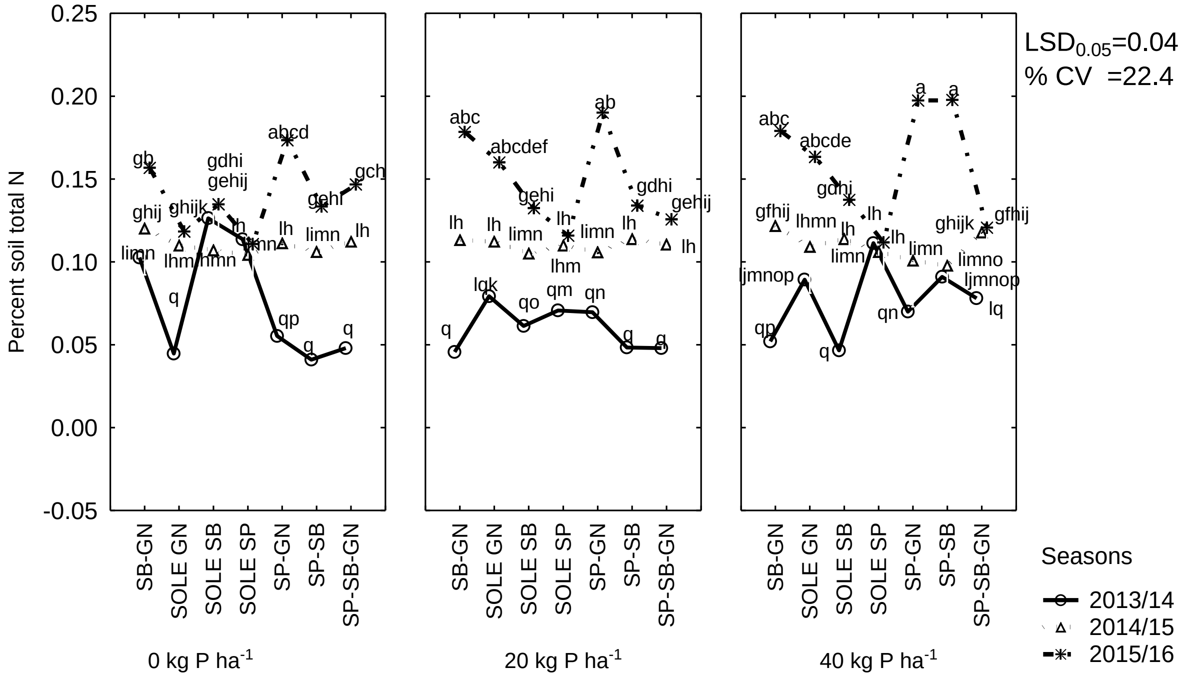
P x seasons	**pH (H_2O)**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	7.10^{a}	6.38^{d}	6.54^{c}	**6.67**
P20	7.07^{a}	6.34^{d}	6.65^{b}	**6.69**
P40	7.09^{a}	6.35^{d}	6.74^{b}	**6.73**
Mean	**7.09**	**6.36**	**6.64**	**6.70**
% CV	**2.3**			
P x seasons $LSD_{0.05}$	**0.09**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

3.3.3 Percent total N

Sole sweetpotato at 0 kg P ha^{-1} in 2013/14 growing season had significantly higher percent total N in the soil than sweetpotato-groundnut intercropping but in 2015/16 growing season sweetpotato- groundnut had a significantly higher percent total N left in the soil compared to plots with sole sweetpotato crop (P=0.038) (Fig 3.1). Sweetpotato- soybean and sole sweetpotato at 40 kg P ha^{-1} had no significant difference in the 2013/14 and 2014/15 growing seasons but sweetpotato- soybean intercropping had a significantly higher percent total N in the soil in the 2015/16 growing season (P=0.038) (Fig 3.1). Treatment plots with sweetpotato-groundnut, intercropping at 20 and 40 kg P ha^{-1} in the 2015/16 growing season had a significantly higher percent total N than plots with sole sweetpotato but in the 2013/14 and

2014/15 growing seasons there was no significant difference in percent total N in the soil at both 20 and 40 kg P ha^{-1} among these treatments (Fig 3.1) (P=0.038). There was a significantly higher percent total N in the soil in 2015/16 at 20 kg P ha^{-1} growing season compared to 2013/14 in all treatments (Fig 3.1). Intercropping x P x season interaction was significant for percent total N in the soil (P=0.038) (Table 3.2).



SB-GN-soybean-groundnut, SOLE GN- sole groundnut, SOLE SB-sole soybean, SOLE SP-sole sweetpotato, SP-GN-sweetpotato-groundnut, SP-SB-sweetpotato-soybean, SP-SB-GN-sweetpotato-soybean-groundnut
Lines indicated with the same letter do not differ significantly at P=0.05.

Figure 3.1. Effect of intercropping sweetpotato, groundnut and soybean at varying P levels on percent soil total N at Umbeluzi research station during 2013/14, 2014/15 and 2015/16 growing seasons.

3.3.4 Percent mineral N

Sweetpotato- groundnut intercropping had no significant difference with sole sweetpotato at 20 and 40 kg P but at 0 kg P ha^{-1} sweetpotato- groundnut had a significantly higher mineral N remaining in the soil than in treatment plots were sole sweetpotato was grown(P=0.01) (Table 3.5). Sole sweetpotato plots and soybean- groundnut intercropping had no significant difference at 0 and 20 kg P ha^{-1} but at 40 kg P ha^{-1}, soybean –groundnut intercropping had a significantly higher mineral N in the soil than sole sweetpotato (P=0.01) (Table 3.5). On average there was a 31.3 % and 25 % increase in mineral N in soybean- groundnut intercropping and sweetpotato- groundnut intercropping respectively compared to sole sweetpotato cropping system (Table 3.5). Intercropping x P interaction was significant for mineral N (P=0.01) (Table 3.2).

Table 3.5. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on percent mineral N in the soil at Umbeluzi research station during 2013/14, 2014/15 and 2015/16 growing seasons

Intercropping x P	**Percent mineral N**			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole sweetpotato	0.026[c]	0.031[bc]	0.038[bc]	**0.032**
Sole soybean	0.027[bc]	0.036[bc]	0.034[bc]	**0.032**
Sole groundnut	0.032[bc]	0.034[bc]	0.028[bc]	**0.031**
Sweetpotato- groundnut	0.044[abc]	0.034[bc]	0.043[abc]	**0.04**
Sweetpotato- soybean	0.039[bc]	0.033[bc]	0.037[bc]	**0.036**
Soybean – groundnut	0.026[c]	0.038[bc]	0.062a	**0.042**
Sweetpotato-groundnut- soybean	0.034[bc]	0.034[bc]	0.047[ab]	**0.038**
Mean	**0.032**	**0.034**	**0.041**	**0.036**
% CV	**46.3**			
Intercropping x P LSD$_{0.05}$	**0.02**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

There was a significantly higher percent mineral N in the soil in the 2013/14 growing season than 2014/15 growing season (P=0.0001) (Table 3.6). Mineral N was significantly higher in the 2015/16 growing season than in the 2014/15 growing season but significantly lower than in the 2013/14 growing season (P=0.0001) (Table 3.6).

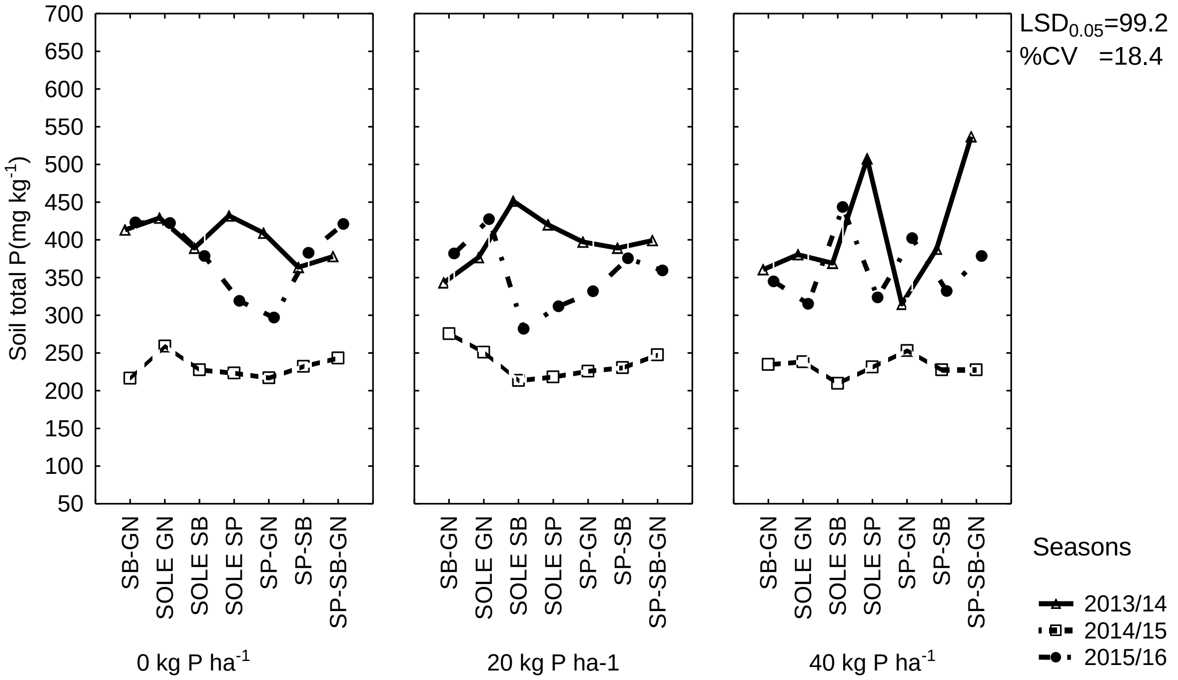
Table 3.6. Effect of seasons on percent mineral N

Growing season	**Percent mineral N**
2013/14	0.062[a]
2014/15	0.019[c]
2015/16	0.028[b]
Mean	**0.036**
% CV	**46.3**
LSD$_{0.05}$	**0.006**

Means with at least a common letter are not significantly different, LSD$_{0.05}$

3.3.5 Soil total P

Plots with sole sweetpotato at 40 kg P ha^{-1} had a significantly higher total P than sweetpotato-groundnut intercropping in the 2013/14 growing season but sweetpotato- groundnut intercropping had significantly higher total P in the soil than in sole sweetpotato in 2015/16 growing season (P=0.023) (Fig 3.2). Sole sweetpotato at 0 kg P ha^{-1} had a significantly .higher total P than sweetpotato- soybean in the 2013/14 growing season but sweetpotato- soybean intercropping had significantly higher total P than sole sweetpotato crop in the 2015/16 growing season (P=0.023) (Fig 3.2). Intercropping x P x season interaction was significant for soil total P (P=0.023) (Table 3.2).

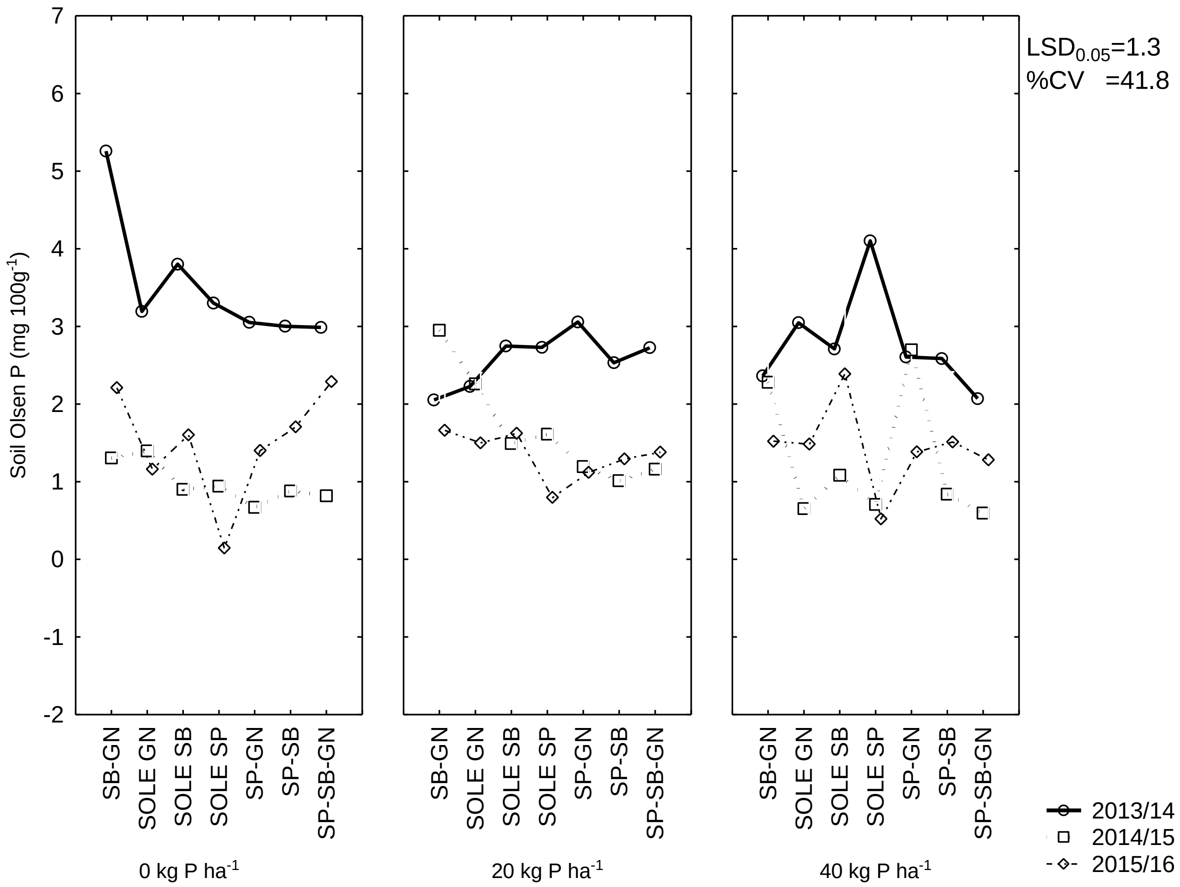


SB-GN-soybean-groundnut, SOLE GN- sole groundnut, SOLE SB-sole soybean, SOLE SP-sole sweetpotato, SP-GN-sweetpotato-groundnut, SP-SB-sweetpotato-soybean, SP-SB-GN-sweetpotato-soybean-groundnut

Figure 3.2. Effect of intercropping sweetpotato with groundnut and soybean at varying P levels on soil total P at Umbeluzi research station during 2013/14, 2014/15 and 2015/16 growing seasons.

3.3.6 Olsen P

In 2013/14, sole sweetpotato at 40 kg P ha^{-1} had a significantly higher Olsen P than sweetpotato- groundnut and soybean- groundnut intercropping but sweetpotato- groundnut and soybean- groundnut intercropping had a significantly higher Olsen P than sole sweetpotato in the 2014/15 growing season. (P=0.023) (Fig 3.3).



SB-GN-soybean-groundnut, SOLE GN- sole groundnut, SOLE SB-sole soybean, SOLE SP-sole sweetpotato, SP-GN-sweetpotato-groundnut, SP-SB-sweetpotato-soybean, SP-SB-GN-sweetpotato-soybean-groundnut

Figure 3.3. Effect of intercropping sweetpotato with groundnut and soybean at varying P levels on soil Olsen P at Umbeluzi research station during 2013/14, 2014/15 and 2015/16 growing seasons.

3.3.7 Soil total K

There was no significant difference in soil total K between sole sweetpotato and sole soybean, sole groundnut, sweetpotato- soybean, soybean- groundnut and sweetpotato- soybean-groundnut in the 2013/14 growing season but in 2015/16 growing season sole soybean, sole groundnut, sweetpotato- soybean, soybean- groundnut and sweetpotato- groundnut- soybean treatments had a significantly higher soil total K than in sole sweetpotato plots (P=0.0001) (Table 3.7). There was a higher soil total K in the 2015/16 than 2014/15 growing seasons for the treatments soybean- groundnut intercropping, sole groundnut and sole soybean and the rest of the treatments did not show any significant difference between the 2014/15 and 2015/16 growing seasons (P=0.0001) (Table 3.7). There was a significantly higher soil total K in the 2014/15 than 2013/14 growing seasons for all treatments (P=0.0001) (Table 3.7). Sole sweetpotato had a 36.3 % and 61.7 % lower soil total K than sweetpotato- soybean and sweetpotato- groundnut- soybean intercropping respectively in the 2015/16 growing season (P=0.0001) (Table 3.7).

Table 3.7. Effect of intercropping sweetpotato, groundnut and soybean on soil total K during 2013/14/ 2014/15 and 2015/16 growing seasons at Umbeluzi research station

Intercropping x seasons	**Total K (meq 100g-1)**			
	Growing seasons			
Intercropping	**2013/14**	**2014/15**	**2015/16**	**Mean**
Sole sweetpotato	1.42^{e}	3.6^{d}	3.6^{d}	**2.9**
Sole soybean	1.52^{e}	3.7^{d}	5.5^{ab}	**3.6**
Sole groundnut	1.84^{e}	3.93^{cd}	5.27^{ab}	**3.7**
Sweetpotato- groundnut	0.94^{e}	4.65^{abcd}	4.53^{bcd}	**3.4**
Sweetpotato- soybean	0.84^{e}	5.63^{ab}	4.91^{abc}	**3.8**
Soybean- groundnut	1.56^{e}	3.68^{d}	5.81^{a}	**3.7**
Sweetpotato- groundnut- soybean	0.93^{e}	5.42^{ab}	5.82^{a}	**4.1**
Mean	**1.30**	**4.4**	**5.1**	**3.6**
% CV	**34.9**			
Intercropping x season LSD $_{0.05}$	**1.2**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

3.3.8 Soil available K

There was higher soil available K on soybean- groundnut and sweetpotato–soybean intercropping at 20 kg P ha^{-1} than the same intercropping combination at 0 kg P ha^{-1} with 15 % and 19 % increase respectively. (P=0.049) (Table 3.8). Sole sweetpotato at 0 kg P ha^{-1} had no significant difference in available K with soybean- groundnut intercropping but at 40 kg P ha^{-1}, soybean- groundnut intercropping had a significantly higher available K than in plots with sole sweetpotato (P=0.049) (Table 3.8). Intercropping x P interaction was significant for available K in the soil (P=0.049) (Table 3.2).

Table 3.8. Effect of intercropping sweetpotato, groundnut and soybean on soil available K.

Intercropping x P	**Available K (meq 100g^{-1})**			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole sweetpotato	0.55^{c}	0.63^{abc}	0.61^{abc}	**0.60**
Sole soybean	0.65^{ab}	0.65^{ab}	0.65^{ab}	**0.65**
Sole groundnut	0.69^{a}	0.60^{bc}	0.66^{ab}	**0.65**
Sweetpotato-groundnut	0.62^{abc}	0.61^{abc}	0.63^{abc}	**0.62**
Sweetpotato-soybean	0.58^{bc}	0.69^{a}	0.58^{bc}	**0.62**
Soybean – groundnut	0.60^{bc}	0.69^{a}	0.63^{abc}	**0.64**
Sweetpotato- groundnut-soybean	0.60^{bc}	0.63^{abc}	0.60^{bc}	**0.61**
Mean	**0.61**	**0.64**	**0.62**	**0.63**
% CV	**13.1**			
Intercropping x P LSD$_{0.05}$	**0.08**			

Means with at least a common letter are not significantly different, LSD0.05

Intercropping x season interaction was significant for soil available K (P<0.001) (Table 3.2). Sole sweetpotato, sweetpotato- groundnut, sweetpotato- soybean and sweetpotato- soybean-groundnut intercropping had no significant difference in soil available K with soybean-groundnut and sole groundnut in the 2013/14 and 2014/15 growing seasons but in 2015/16 growing season soybean- groundnut and sole groundnut had a significantly higher soil available K than sole sweetpotato, sweetpotato- groundnut, sweetpotato- soybean and sweetpotato - groundnut- soybean intercropping (P<0.001) (Table 3.9).

Table 3.9. Effect of intercropping sweetpotato, groundnut and soybean on available K at Umbeluzi research station during 2013/14. 2014/15 and 2015/16 growing seasons.

Intercropping x seasons	**Available k (meq 100g^{-1})**			
	Growing seasons			
Intercropping	**2013/14**	**2014/15**	**2015/16**	**Mean**
Sole sweetpotato	0.57^{cde}	0.51^{e}	0.72^{b}	**0.6**
Sole soybean	0.54^{cde}	0.6^{cd}	0.82^{a}	**0.65**
Sole groundnut	0.56^{cde}	0.52^{de}	0.87^{a}	**0.65**
Sweetpotato-groundnut	0.60^{cd}	0.55^{cde}	0.70^{b}	**0.62**
Sweetpotato-soybean	0.61^{c}	0.53^{cde}	0.70^{b}	**0.61**
Soybean-groundnut	0.56^{cde}	0.53^{cde}	0.82^{a}	**0.64**
Sweetpotato-groundnut-soybean	0.60^{cd}	0.54^{cde}	0.70^{b}	**0.61**
Mean	**0.58**	**0.54**	**0.76**	**0.63**
% CV	**13.1**			
Intercropping x season LSD $_{0.05}$	**0.08**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

There was no significant difference in soil available K among the three P levels in the 2013/14 and 2014/15 growing seasons but both at 20 and 40 kg P ha^{-1} had a significantly higher soil available K than at 0 kg P ha^{-1} in the 2015/16 growing season (P=0.02) (Table 3.10). Increasing P from 0 to 20 kg ha^{-1} resulted in 12.9 % increase in available K in the 2015/16 growing season (Table 3.10). There was no significant difference in soil available K between 20 and 40 kg P ha^{-1} in all seasons (P>0.05) (Table 3.10).

Table 3.10. Effect of seasons at three P levels on soil available K

P x seasons	**Available K(meq 100^{-1})**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	0.58^{c}	0.54^{cd}	0.70^{b}	**0.61**
P20	0.58^{c}	0.56^{cd}	0.79^{a}	**0.64**
P40	0.56^{cd}	0.52^{d}	0.79^{a}	**0.62**
Mean	**0.57**	**0.54**	**0.76**	**0.62**
% CV	**13.1**			
P x seasons $LSD_{0.05}$	**0.05**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

3.3.9 Soil CEC

For sole sweetpotato and soybean there were no significant differences in CEC at 0, 20 and 40 kg ha^{-1} P. However, for sole groundnut, sweetpotato- groundnut, sweetpotato- soybean and soybean –groundnut intercrops, CEC was significantly lower at 0 kg ha^{-1} P, and increased with increasing P application, and soil CEC was highest at 40 kg ha^{-1} P. For the sweetpotato - groundnut- soybean intercrop, CEC was not significantly different between the 0 and 20 kg ha^{-1} P, though the CEC was significantly lower than the 40 kg ha^{-1} P.

Across treatments at 40 kg P ha^{-1}, sweetpotato- soybean intercropping had the highest CEC (Table 3.11). Sweetpotato- groundnut and sweetpotato- soybean had a significantly higher CEC than sole sweetpotato at 40 kg P ha^{-1} with an increase of 21 % and 25.3 % in CEC respectively compared to sole sweetpotato (P=0001) (Table 3.11). Sweetpotato- groundnut intercropping at 40 kg P ha^{-1} had a significantly higher CEC of 42.9 % compared to 0 kg P ha^{-1} (Table 3.11). Intercropping x P interaction was significant for CEC (P=0.0001) (Table 3.2).

Table 3.11. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on cation exchange capacity in the soil.

Intercropping x P	**CEC(meq 100g^{-1})**			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole sweetpotato	31.5^{de}	28.7^{efg}	30.0^{def}	**30.1**
Sole soybean	30.0^{def}	28.7^{efg}	30.1^{de}	**29.6**
Sole groundnut	23.7^{i}	32.7^{bcde}	28.6^{efgh}	**28.3**
Sweetpotato- groundnut	25.4^{fghi}	32.2^{cde}	36.3^{abc}	**31.3**
Sweetpotato- soybean	28.3^{efghi}	30.9^{de}	37.6^{a}	**32.3**
Soybean – groundnut	24.4^{ghi}	37.1^{ab}	33.6^{abcd}	**31.7**
Sweetpotato-groundnut- soybean	28.1^{efghi}	24.0^{hi}	32.1^{cde}	**28.1**
Mean	**27.3**	**30.6**	**32.6**	**30.2**
% CV	**16.5**			
Intercropping x P LSD$_{0.05}$	**4.6**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

The CEC varied with season (P=0.001) (Table 3.2). There was significantly higher CEC in the 2015/16 growing season than in both the 2013/14 and 2014/15 growing seasons (P=0.001) (Table 3.12). There was a 16.5 % increase in CEC from the 2013/14 to 2015/16 growing seasons. There was significantly higher CEC in the 2014/15 than 2013/14 growing seasons with an 8.6 % increase (P=0.001) (Table 3.12).

Table 3.12. Effect of seasons on soil CEC at Umbeluzi research station in the 2013/14. 2014/15 and 2015/16 growing seasons.

Growing season	**CEC (meq 100g^{-1})**
2013/14	27.8^{c}
2014/15	30.2^{b}
2015/16	32.4^{a}
Mean	**30.1**
% CV	**16.5**
LSD$_{0.05}$	**1.8**

Means with at least a common letter are not significantly different, LSD$_{0.05}$

3.4 Discussion

Results of the study indicate that intercropping and P application has some influence on soil chemical properties**.** Soil pH decreased in all treatments involving legumes in the mix by 2015/16 growing season. This could have been caused by proton release in the rhizosphere by legumes in the intercropping treatments by the end of the 2013/14 growing season that acidified the soil compared to sole sweetpotato. Work by Yan et al. (1996) and Li et al. (2007) showed that soil is acidified due to excretion of large quantities of organic acids or H^+ from plant roots resulting from excess uptake of cations over anions in the N fixation process. The results are more important in high pH and calcareous soils where the presence of $CaCO_3$ directly or indirectly affects the chemistry and availability of N, P, Mg, K, Mn, Zn and Fe. The nutrient uptake by plants is governed by numerous soil factors. Among them, high soil pH and $CaCO_3$ contents are predominantly responsible for low availability of particular plant nutrients (Kaya et al 2009). Application of N, P and K fertilizer alone cannot resolve the nutrient deficiency and P fixation under high soil pH. Therefore pH reduction through legume intercropping systems may contribute to availability of nutrients that are important in sweetpotato production systems in Mozambique and farmers can exploit this cropping system to exploit soil nutrients that are in some instances unavailable due to high pH.

Intercropping and P application are effective means of increasing mineral N in the soil through N fixation**.** Intercropping soybean- groundnut, sweetpotato- groundnut and sweetpotato - groundnut- soybean at 40 kg ha^{-1} resulted in higher mineral N in 2013/14 growing season compared to plots with sole sweetpotato crop. This suggests that intercropping has some positive effects on mineral N probably from N- fixation (Shoko et al. 2007). The nodulation process is probably encouraged by P in intercropping combinations involving legumes in the mix resulting in higher mineral N.

The results of the study indicated that farmers can save on N fertiliser through sweetpotato-groundnut intercropping and sweetpotato- soybean intercropping at 40 kg P $ha^{-1.}$ Sole sweetpotato (control) resulted in less N compared to the intercrops mentioned above. This may be due to the balance of chemical fertilizer N, biological N_2 fixation by legumes, crop residues and root incorporation into the soil at the end of each growing season. Wang et al. (2014)

reported similar results that intercropping did not reduce soil total N in continuous mono-cropping and high nitrogen removal from soil for several years. Previous studies have shown that a higher proportion of N in legumes is derived from atmospheric N_2 fixation in intercrops than in monocrop (Jensen 1996). In addition, Jensen and Hauggaard-Nielsen (2003) working on crop residues incorporation reported that crop residues provided approximately 40 kg ha^{-1} N accumulation in soil which contributed to total N. Application of P at 40 kg ha^{-1} probably stimulated nodulation resulting in N fixation in the soil (Shoko et al. 2007). Sweetpotato farmers in Mozambique are recommended to apply P fertiliser at 40 kg ha^{-1} in sweetpotato-groundnut, sweetpotato-soybean and sweetpotato- groundnut- soybean intercropping system with the view of improving nodulation and hence N fixation as fully supported by Ojo et al. (2016). Fustec et al. (2010) reported that legumes grown in intercropping could probably serve as a sustainable and alternative way of introducing soil N into lower input agro ecosystems by smallholder farmers.

Soil total P in sweetpotato- groundnut and sweetpotato- soybean intercropping was significantly higher in the 2015/16 growing season than in sole sweetpotato. A similar trend occurred with Olsen P. These could have been caused by a modification of the rhizosphere environment of intercropped legumes in this study and ultimately benefiting sweetpotato by increasing P mobilization. These findings are in line with reports by Ae et al. (1990) and Xia et al. (2013) that legume roots secrete piscidic acid which promotes the release of P from $FePO_4$ by chelating iron thereby increasing amount of P in the soil. This finding suggested that cultivation of soybean and groundnut increased phosphorus availability for plant uptake. Farmers can therefore take advantage of this mechanism to ensure adequate P in soils with low inherent P. An increase in total and Olsen P in the 2015/16 growing season in this study could have been caused by mineralization of organic matter from crop residues that were incorporated into the soil at the end of the 2013/14 and 2014/15 growing seasons thereby providing phosphorus to the soil through P recycling. Crop residues from the two legumes in this study could have contributed more P to the soil through rapid decomposition hence more total and Olsen P in cropping systems involving legumes in the mix. This observation is fully in agreement with findings by Lupwayi et al. (2003) that the release of P from crop residues is influenced by not only the P content of the residue, but the ease of decomposition. Overall, this study has highlighted the potential role that legumes and crop residues, either alone or in combination with inorganic P, can play in increasing P in soils. Farmers can adopt this technology in their sweetpotato production system with the view of improving P soil content that is necessary for nodulation in groundnut and soybean and sweetpotato vegetative growth as demonstrated in Chapter 4 of this thesis.

Sweetpotato production require a very high amount of soil K because leaves, vines, stems and storage roots usually remove substantial quantity of K from the soil (Uwah et al. (2013). The results of the current study indicated an increase in both soil total and available K in 2014/15 and 2015/16 respectively in legume systems compared to sole sweetpotato cropping system. Additional amount of total and available K in the soil at the end of the 2015/16 growing season could have come from the crop residues that were incorporated into the soil at the end of each growing season. A study by Lupwayi et al. (2005) working on the impact of previous crop on the input and release of K from green manure, field pea, canola, and wheat crop residues revealed that more than 90 % of crop residue K was released to the soil within one year of addition.

Soil available K was particularly higher on soybean-groundnut intercropping, sole groundnut and sole soybean than sole sweetpotato and any other intercropping combination involving sweetpotato in the mix in the 2015/16 growing season. This was probably because the legumes did not mine as much K from the soil as sweetpotatoes resulting in more K remaining in the soil. The study by Uwah et al. (2013) showed that for optimum yield sweetpotato requires 160 kg K ha^{-1}. These results are significant for sweetpotato farmers in Mozambique because one of the limiting factors in sweetpotato yield is soil available K. Therefore farmers may need to intercrop sweetpotato with legumes and incorporate crop residues into the soil with the view of recycling K back to the soil for use in the following season. This will save the farmers on money to annually buy K fertilizers in sweetpotato production system over and above the yield benefits that are associated with sweetpotato-legume intercropping system.

Cation exchange capacity (CEC) was higher at 40 kg P ha^{-1} than at 0 kg P ha^{-1} in soybean-groundnut, sweetpotato- groundnut and sweetpotato- soybean intercropping combinations. The application of 40 kg P probably stimulated growth of the component crops that subsequently produced high amount of crop residues at the end of each growing season. The incorporated crop residues probably improved soil organic matter content which subsequently improved soil CEC. In addition sweetpotato- groundnut and sweetpotato- soybean intercropping had a higher CEC than sole sweetpotato probably because of high amount of biomass produced by the intercropping system that was incorporated into the soil thereby increasing CEC. The current findings are fully supported by Ogbodo (2011) who worked with crop residues and reported increases in soil CEC and soil nutrients on residue treated soils compared to the untreated ones. An improvement in CEC through sweetpotato- legume intercropping with P application and incorporation of crop residues into the soil is an important management practice in soil fertility improvement as this would probably increase yields and food security among smallholder sweetpotato farmers in Mozambique.

3.5 Conclusion

Sweetpotato- legume intercropping and P application contributes to N fixation and soil pH reduction and may contribute to availability of some nutrients such as Zn and Fe that may not be available due to high pH. Application of P and nutrient cycling through incorporation of crop residues is an important part of integrated nutrient management that helps to improve soil CEC, P and K that should be encouraged in sweetpotato cropping systems.

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Chapter 4 : Effect of intercropping sweetpotato with groundnut and soybean at three P levels on vegetative growth

Abstract

Vegetative growth influences crop yield and therefore ensure food security. A study was carried out to assess the effects of intercropping sweetpotato with groundnut and soybean at different P application levels, on vegetative growth of OFSP variety, groundnut and soybean at Umbeluzi research station during the 2013/14, 2014/15 and 2015/16 growing seasons. The experiment was a 7 x 3 factorial in split plot arrangement. The main plot treatments were sole sweetpotato, sole groundnut, sole soybean, sweetpotato- groundnut, sweetpotato- soybean, sweetpotato- groundnut- soybean, groundnut-soybeans intercropping. The subplot treatments were 0, 20 and 40 kg P ha^{-1} applied at planting. Sweetpotato- soybean intercropping at 20 kg P ha^{-1} increased main stem length compared to sole sweetpotato at the same P level in all growing seasons. There was 10 % higher main stem length in sweetpotato- soybean intercropping at 20 kg P ha^{-1} compared to sole sweetpotato in the 2015/16 growing season. There was no significant difference in stem length between 20 and 40 kg P ha^{-1} in the intercropping treatments. Sweetpotato- groundnut and sweetpotato- soybean intercropping at 40 kg P ha^{-1} increased fresh root mass plant^{-1} compared to sole sweetpotato crop at the same P level in the 2013/14 and 2014/15 growing season. Sweetpotato- soybean- groundnut, sweetpotato- soybean and sweetpotato- groundnut intercropping at 0 and 40 kg P ha^{-1} increased number of leaves plant^{-1} compared to sole sweetpotato. Stem diameter on sole sweetpotato at all P levels was more than sweetpotato- soybean intercropping. Stem diameter at 20 kg P ha^{-1} was more than at 0 kg P ha^{-1} on all intercropping combinations. Sole sweetpotato increased stem diameter compared to sweetpotato- soybean intercropping in both the 2013/14 and 2014/15 growing seasons. Number of nodules plant^{-1} in groundnut was higher at 40 kg P ha^{-1} than 20 kg P ha^{-1} in all the growing seasons. Soybean depressed number of leaves plant^{-1} in groundnut in

soybean-groundnut intercropping. Number of nodules plant^{-1} in soybean was significantly higher at 40 kg P ha^{-1} than 0 kg P ha^{-1} in all treatments. Groundnut- soybean at 0 and 20 kg P ha^{-1} had a significantly higher soybean stem diameter than sweetpotato-soybean intercropping. The results suggests that both intercropping and P application positively increased sweetpotato vegetative growth. Smallholder farmers may consider sweetpotato- soybean- groundnut, sweetpotato- soybean and sweetpotato- groundnut intercropping as increased vegetative growth and translate to higher yields of sweetpotatoes, and also available leaves for consumptions as vegetables.

Key words: groundnut, soybean, sweetpotato, Vegetative growth

4.1 Introduction

Smallholder agriculture in sub Saharan Africa is characterised by many farming systems ranging from mono-cropping to a variety of intercropping practises (Garrity et al. 2012). Intercropping has the potential to achieve higher crop yields than monoculture systems. Enhanced productivity of intercropping compared with monoculture can be explained by two major processes that result in improved resource use: complementarity and facilitation (Fridley 2001). Complementarity is a decrease in interspecific competition and competitive exclusion through resource partitioning between intercropped species (Hinsinger et al. 2011). Facilitation occurs when one species enhances the growth or survival of another (Callaway 1995). This occurs through (1) direct positive mechanisms, such as favourable alteration of temperature, light, soil moisture, and nutrients and (2) indirect mechanisms, such as beneficial changes in soil mycorrhizal or microbial communities (Callaway 1995).

The system of cropping pattern depends on land availability, crops planted and farming culture. Sweetpotato, groundnuts and soybean are more often planted in intercrops with cereals and tuber crops. Despite their nutritional importance these crops are planted in poor soils with no major soil nutrient elements especially phosphorus (P). Phosphorus is an essential constituent of many organic compounds such as ADP, NADP, ATP, that are very important for metabolic processes, among them respiration and photosynthesis that is essential for root growth, particularly lateral roots and fibrous rootlets (Kareem 2013). Global demand for P fertilizer continues to increase while global reserves of P are in decline (Cordell et al. 2009) due to several reasons such as erosion and fixation.

The availability of soil P for plants is related to several plant characters, including the release of carboxylates (Ryan et al. 2001), morphological traits such as early root development, root length and surface area of roots (Li et al. 2007), root architecture, root hair development (Gahoonia and Nielsen 1997), mycorrhizas and specialized structures such as root clusters (Lambers et al. 2003; Shane and Lambers 2005). Long roots and high root surface enable the plant to scavenge for nutrients especially P that is relatively immobile in the soil thereby providing a plant with a competitive edge for soil nutrients and water (Rashid and Waithaka 2009). Strong roots support nodules, sites for N fixation in legumes and is essential for water acquisition especially during water stress periods resulting in improved vegetative growth and yield of soybeans (Cassman et al. 1980). Deep rooting and proliferation is an adaptive trait in groundnuts and soybean growing under water stress environments (Vadez et al. 2007). Root interception of nutrients in the soil can be increased by root proliferation, increased frequency and length of root hairs in soybeans. Groundnuts and soybeans exhibit higher P-acquisition efficiency than other crops due to cluster-root formation and release of carboxylates (Bolland et al. 1999). In an intercropping system underground root/rhizosphere interaction plays an essential role in P uptake and biomass production (Li et al. 2007, Li et al. 2011). The objective of the current study was to assess the effects of intercropping OFSP with soybean and groundnut at three P application levels on vegetative growth of orange fleshed sweetpotato, groundnut and soybean.

4.2 Materials and methods

4.2.1 Location and varieties

The intercropping experiments were conducted at Umbeluzi research station in the 2013/14, 2014/15 and 2015/16 growing seasons. A sweetpotato variety Namanga, was used in this experiment because of its adaptability to the local environment and high consumer preference. Soybean and groundnut varieties that were used in this experiment were Zamboane and Bibiana vermelho respectively. These two legumes were selected due to their high nitrogen fixation capacities, tolerance to the local environment and high protein content.

4.2.2 Experimental site and design

Experimental site description, location and design is given in section 3.2.3 in Chapter 3 of this thesis.

4.2.3 Traits measured

In the sweetpotato crop at 10 weeks after planting, main stem length was measured non-destructively by randomly selecting 5 plants per replication in the net plot (middle ridges) followed by placing a ruler alongside the plant from the point of soil contact to the apical tip and read the length of the plant in its natural position (Heady 2007). This was repeated by placing a string along the plant length and measure the length of the string using a tape measure to confirm the measurement by a ruler from the point of soil contact to the apical tip (Laurie et al. 2015). The mean length of the plants in every replication was then calculated.

Number of leaves plant^{-1} was determined non-destructively through physical counting of leaves from 3 plants that were selected at random from each replication. The mean number of leaves of the plants in every replication was then calculated.

Sweetpotato fresh root mass was determined by randomly selecting 3 plants from the net plot and carefully removing them from the soil and washing off the loose soil. The roots were separated from the plant using a stainless blade and then blotted gently with soft paper towel to remove any free surface moisture. The fresh roots were then weighed immediately using an electrical sensitive balance and mean fresh root mass was determined. Stem diameter was determined non-destructively by selecting 3 plants at random from each replication and measuring the stem diameter at 40 cm from the point of soil contact using a Vernier callipers (Kaur 2014).

In the groundnut crop, the number of days to first flowering-was determined by direct observation daily in the morning at 0800 and afternoon at 1600 in each replication and recording the number of days since planting when the first flower appeared in the net plot. Number of nodules plant^{-1}in the first 10 cm were determined by randomly selecting 3 groundnut plants from each replication and carefully pulling them from the soil and cleaned them with running water to expose all the roots and nodules. The nodules were then counted physically and a mean number of nodules plant^{-1} was recorded. The number of leaves plant^{-1} was determined non-destructively by randomly selecting 3 plants from each replication and physically counting the number of leaves and the mean number of leaves was calculated.

In the soybean crop, plant height, the number of nodules plant^{-1} and stem diameter were determined using the procedures described in the previous section for groundnut.

4.2.4 Data Analysis

Morphological data was analysed using Statistica 13.0. Any treatment means found to be significantly different were separated using Fischer's protected $LSD_{0.05}$.

4. 3 Results

4.3.1. Sweetpotato vegetative growth parameters

Summary of ANOVA and F values for the measured parameters are shown in Table 4.1 and show that intercropping x P interaction significantly affects sweetpotato main stem length, number of leaves plant^{-1}, stem diameter and fresh root mass.

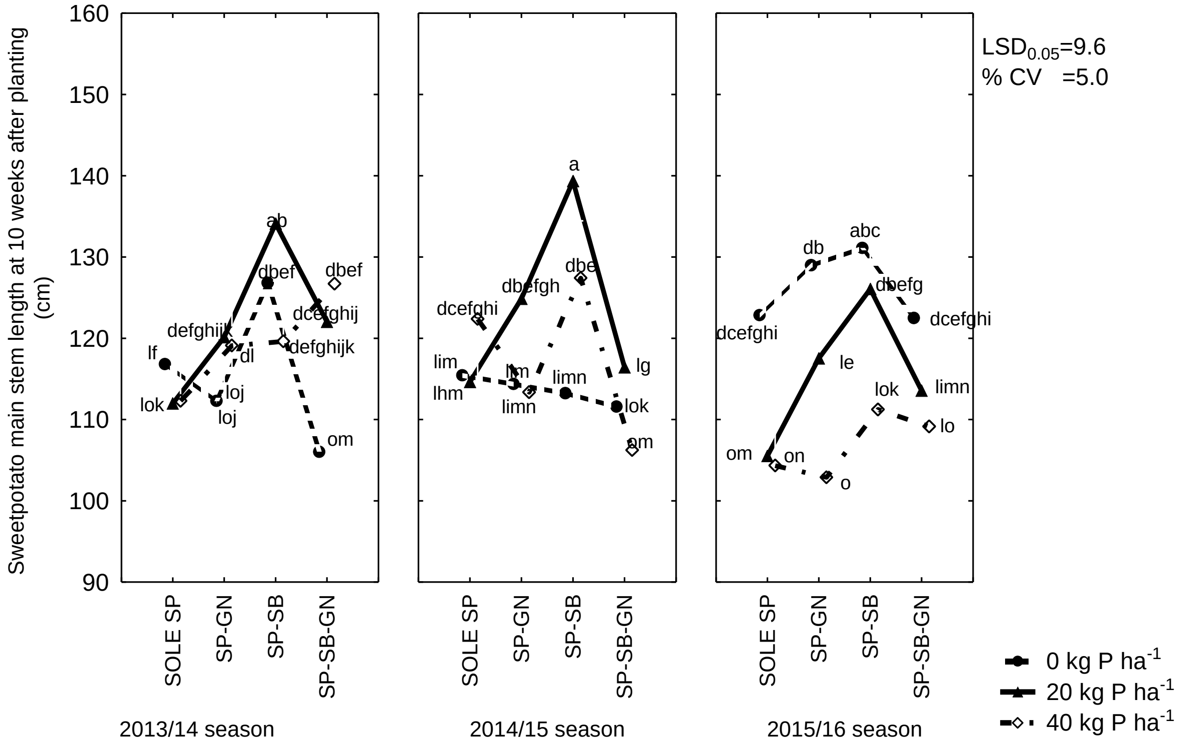
Table 4.1. Summary of significant effects (F- values) from the analysis of variance done on sweetpotato measured growth parameters at Umbeluzi research station in Mozambique in 2013/14, 2014/15 and 2015/16 growing seasons

Source	Main stem length (cm)	Number of leaves plant-^{1}	Stem diameter (cm)	Fresh root mass (g plant $^{-1}$)
I	***	***	***	***
P	***	***	***	***
S	ns	***	***	***
I x P	***	*	***	***
I x s	ns	ns	***	***
P x s	***	ns	ns	ns
I x P x s	**	ns	ns	***

*, **, *** Significant at P≤0.05, P≤0.01, and P≤0.001 respectively, ns denotes non significance at P≤0.05.
I-intercropping, P-phosphorus S- season, I x P-intercropping x Phosphorus, I x S-intercropping x season, I xP x S-intercropping x Phosphorus x season interaction.

4.3.2 Sweetpotato main stem length

Sweetpotato- groundnut had no significant difference in sweetpotato main stem length at all P levels in the 2013/14 growing but had a significantly higher sweetpotato stem length at 0 kg P ha^{-1} than at both 20 and 40 kg P ha^{-1} in the 2015/16 growing season (Fig 4.1). Sweetpotato-soybean intercropping at 20 kg P ha^{-1} had a significantly higher sweetpotato main stem length than sole sweetpotato at the same P level at 10 weeks after planting in all growing seasons (P<0.001)(Fig 4.1). Intercropping x P x season interaction was significant for main stem length at 10 weeks after planting (P<0.01) (Table 4.1).



SOLE SP-sole sweetpotato, SP-GN-sweetpotato-groundnut, SP-SB-sweetpotato-soybean, SP-SB-GN-sweetpotato-soybean-groundnut

Lines indicated with the same letter do not differ significantly at P=0.05.

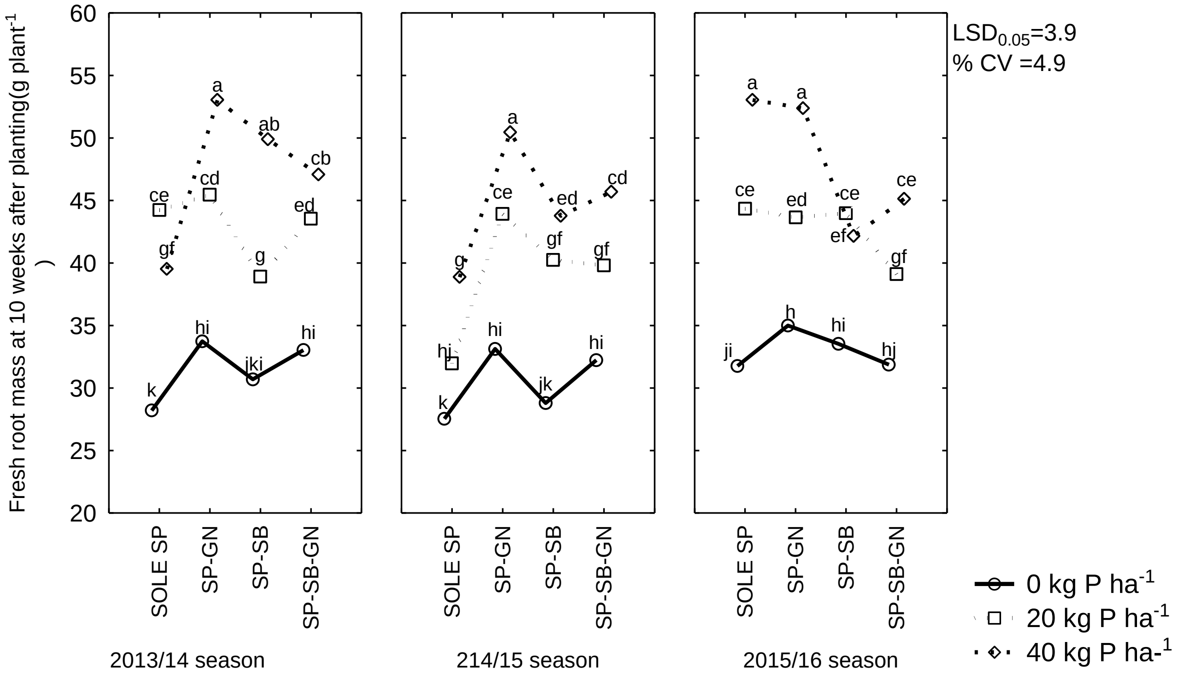
Figure 4.1. Effect on intercropping sweetpotato, groundnut and soybean at three levels on sweetpotato main stem length at 10 weeks after planting at Umbeluzi research station in the 2013/14,2014/15 and 2015/16 seasons.

Sweetpotato- soybean intercropping had a significantly higher sweetpotato main stem length at 10 weeks after planting at 20 kg P ha^{-1} than at 40 kg P ha^{-1} in the 2013/14, 2014/15 and 2016 growing g seasons (P<0.01) (Fig 4.1).

4.3.3 Fresh root mass at 10 weeks after planting

In all intercropping combinations there was a significantly higher fresh root mass plant^{-1} at 20 kg P ha^{-1} than at 0 kg P ha^{-1} in all growing seasons (P=0.0001) (Fig 4.2). Sweetpotato-groundnut intercropping at 40 kg P ha^{-1} had a significantly higher fresh root mass plant^{-1} at 10 weeks after planting than the sole sweetpotato crop at the same P level in the 2013/14 and 2014/15 growing seasons but in the 2015/16 growing season, there was no significant difference between sweetpotato- groundnut and sole cropping systems at 40 kg P ha^{-}

[1](P=0.0001) (Fig 4.2). Intercropping x P x season interaction was significant for sweetpotato fresh root mass at 10 weeks after planting (P=0.0001) (Table 4.1).



SOLE SP-sole sweetpotato, SP-GN-sweetpotato-groundnut, SP-SB-sweetpotato-soybean, SP-SB-GN-sweetpotato-soybean-groundnut
Lines indicated with the same letter do not differ significantly at P=0.05.

Figure 4.2. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on sweetpotato fresh root mass at 10 weeks after planting at Umbeluzi research station during 2013/14, 2014/15 and 2015/16 growing seasons

4.3.4 Number of leaves plant^{-1}

Sweetpotato-soybean had significantly higher number of leaves plant^{-1} than sweetpotato-groundnut at 20 and 40 kg P ha^{-1} but the two had no significant difference at 0 kg P ha^{-1} (Table 4.2). There was a significantly higher number of sweetpotato leaves plant^{-1} at 40 kg P ha^{-1} than at both 0 and 20 kg P ha^{-1} for all intercropping combinations, (P=0.034) (Table 4. 2). Sweetpotato- soybean- groundnut, and sweetpotato- groundnut intercropping had no significant difference in the number of leaves plant^{-1} at 0 and 20 kg P ha^{-1} but at 40 kg P ha^{-1} sweetpotato- soybean- groundnut intercropping had a significantly higher number of leaves plant^{-1} than in sweetpotato- groundnut intercropping (P=0.034) (Table 4.2). Sweetpotato-groundnut and sweetpotato- soybean intercropping at 0 kg P ha^{-1} had 3.6 % and 3.8 % respectively more number of leaves plant^{-1} compared to sole sweetpotato (Table 4.2). Intercropping x P interaction was significant for number of leaves plant^{-1} at 10 weeks after planting in sweetpotato (P=0.034) (Table 4.1).

Table 4.2. Effect of intercropping sweetpotato with groundnut and soybean under varying P levels on sweetpotato number of leaves plant^{-1} at 10 weeks after planting at Umbeluzi research station

Intercropping x P	**Number of leaves plant^{-1}**			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole sweetpotato	251.4^{h}	296.2^{f}	328.2^{c}	**291.9**
Sweetpotato-groundnut	260.4^{g}	307.1^{e}	338.3^{b}	**301.9**
Sweetpotato-soybean	261.0^{g}	316.4^{d}	346.1^{ab}	**307.8**
Sweetpotato -groundnut- soybean	255.4^{gh}	312.1^{de}	352.2^{a}	**306.6**
Mean	**257.1**	**308**	**341.2**	**302.1**
% CV	**3.1**			
Intercropping x P LSD$_{0.05}$	**8.9**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

The number of leaves plant varied with seasons. There was a significantly higher number of leaves plant^{-1} in 2014/15 than both 2013/14 and 2015/16 growing seasons (Table 4.3). There was 5.1 % more sweetpotato leaves plant^{-1} in 2014/15 than 2015/16 growing season (Table 4.3).

Table 4.3. Effect of seasons on sweetpotato number of leaves plant^{-1} at 10 weeks after planting at Umbeluzi research station during 2013/14, 2014/15 and 2015/16 growing season

Growing season	**Number of leaves plant^{-1}**
2013/14	298.3^{b}
2014/15	311.8^{a}
2015/16	296.8^{b}
Mean	**302.3**
%CV	**3.1**
LSD	**5.2**

Means with at least a common letter are not significantly different, LSD$_{0.05}$

4.3.5 Stem diameter at 10 weeks after planting

There was a significantly higher stem diameter in sweetpotato- groundnut intercropping at 20 kg P compared to sole sweetpotato (P=0.0001) but there was no significant difference in stem diameter between sweetpotato- groundnut and sole sweetpotato at 0 and 40 kg P ha^{-1} (P>0.05) (Table 4.4). Sweetpotato- groundnut had 7 % higher sweetpotato stem diameter than sole sweetpotato at 20 kg P ha^{-1} (Table 4.4). Stem diameter on sole sweetpotato was significantly higher than sweetpotato- soybean intercropping at 10 weeks after planting at 0 and 40 kg P ha^{-1} but not significantly different at 20 kg P ha^{-1} (P=0.0001) (Table 4.4). There was a significantly higher stem diameter at 20 kg P ha^{-1} than at 0 kg P ha^{-1} on all intercropping combinations (P=0.0001) (Table 4.4). Intercropping x P interaction was significant for stem diameter at 10 weeks after planting (P=0.0001) (Table 4.1)

Table 4.4. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on sweetpotato stem diameter.

Intercropping x P	**Stem diameter (cm)**			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole sweetpotato	0.76^{gh}	0.86^{de}	0.98^{a}	**0.87**
Sweetpotato- groundnut	0.78^{fg}	0.92^{bc}	0.95^{ab}	**0.88**
Sweetpotato- soybean	0.63^{i}	0.82^{ef}	0.88^{dc}	**0.77**
Sweetpotato- groundnut- soybean	0.72^{h}	0.83^{e}	0.91^{bc}	**0.82**
Mean	**0.72**	**0.86**	**0.93**	**0.83**
% CV	**4.6**			
Intercropping x P LSD$_{0.05}$	**0.04**			

For each parameter, means with at least a common letter are not significantly different, LSD$_{0.05}$

Sole sweetpotato had significantly higher stem diameter than sweetpotato-soybean and sweetpotato- groundnut- soybean intercropping in the 2013/14 and 2014/15 growing seasons but no significant difference was observed between these treatments in the 2015/16 growing season (P=0.024) (Table 4.5). Sweetpotato stem diameter was 14.5 % and 19.4 % higher in sole sweetpotato than sweetpotato- soybean intercropping in 2013/14 and 2014/15 growing season respectively (Table 4.5). There was no significant difference in stem diameter between sole sweetpotato and sweetpotato- groundnut intercropping system in sweetpotato in all growing seasons (P>0.05) (Table 4.5). Intercropping x season interaction was significant for stem diameter at 10 weeks after planting (P=0.024) (Table 4.1).

Table 4.5. Effect of intercropping sweetpotato with groundnut and soybean on stem diameter during 2013/14, 2014/15 and 2015/16 growing seasons at Umbeluzi research station

Intercropping x season	**Stem diameter (cm)**			
	Growing seasons			
Intercropping	**2013/14**	**2014/15**	**2015/16**	**Mean**
Sole sweetpotato	0.87^{ab}	0.86^{b}	0.87^{ab}	**0.87**
Sweetpotato- groundnut	0.88^{ab}	0.86^{b}	0.91^{a}	**0.88**
Sweetpotato- soybean	0.76^{ed}	0.72^{e}	0.84^{bc}	**0.77**
Sweetpotato- groundnut- soybean	0.80^{cd}	0.81^{c}	0.84^{bc}	**0.82**
Mean	**0.83**	**0.81**	**0.87**	**0.84**
% CV	**4.6**			
Intercropping x season LSD $_{0.05}$	**0.04**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

4.3.6 Groundnut vegetative growth parameters

Summary of ANOVA and F values for the measured parameters are shown in Table 4.6. Table 4.6 show that intercropping x P interaction had no significant effects on groundnut number of nodules plant^{-1}, number of days to first flowering and number of groundnut number of leaves plant^{-1}. Intercropping x season interaction significantly affects number of days to flowering and number of leaves plant^{-1}.

Table 4.6. Summary of significant effects (F- values) from the analysis of variance done on groundnut growth parameters measured at Umbeluzi research station in Mozambique in 2013/14, 2014/15 and 2015/16 growing seasons

Source of variation	**Number of nodules plant^{-1}**	**Number of days to first flowering**	**Number of groundnut leaves plant^{-1}**
I	***	***	***
P	***	***	***
S	**	ns	***
I x P	ns	ns	ns
I x S	ns	***	***
P x S	*	ns	ns
I x P x S	ns	ns	ns

*,**, *** denote significance at $P \le 0.05$, $P \le 0.01$, $P \le 0.001$ respectively and ns denotes non significance at $P \le 0.05$.

I-intercropping, P-phosphorus S- season, I x P-intercropping x Phosphorus, I x S-intercropping x season, I xP x S-intercropping x Phosphorus x season interaction.

4.3.7 Number of nodules plant^{-1} in groundnut

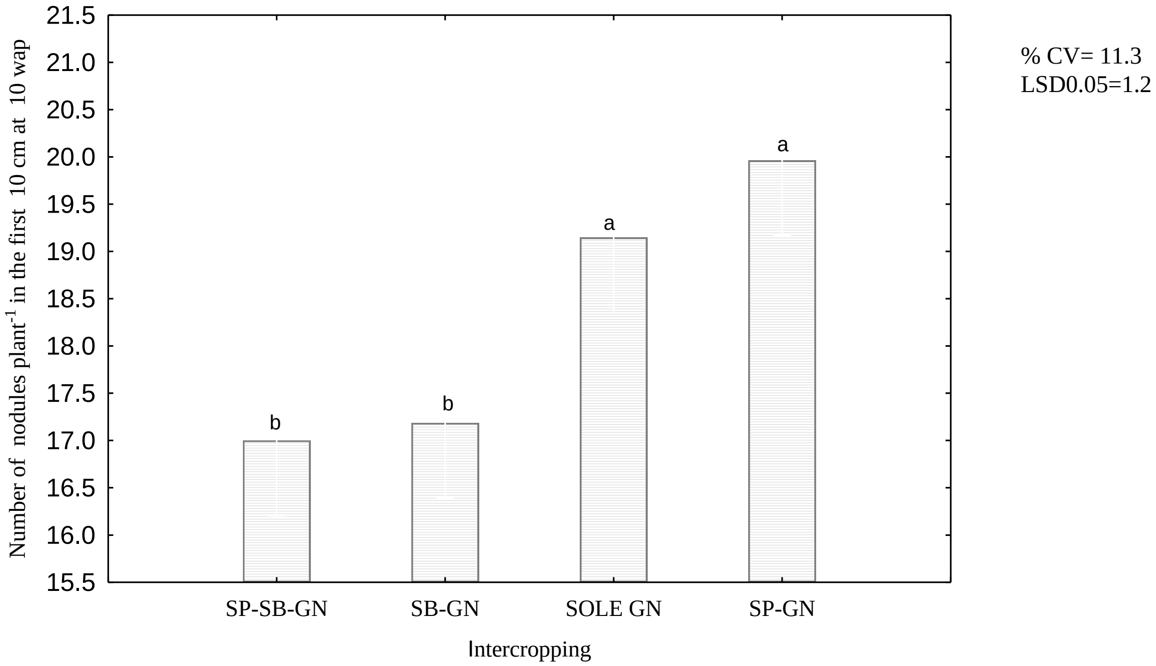
There was a significantly higher number of nodules plant^{-1} at 20 and 40 kg P ha^{-1} than at 0 kg P ha^{-1} in all the growing seasons (P=0.021) (Table 4.7). Number of nodules plant^{-1} was 20.1 %, 17.4 % and 25.7 % higher at 40 kg P ha^{-1} than 20 kg P ha^{-1} in 2013/14, 2014/15 and 2015/16 growing seasons respectively (P=0.021) (Table 4.7). There was a significantly higher number of nodules plant^{-1} in 2015/16 growing season than in the 2013/14 and 2014/15 growing season at 0 kg P ha^{-1}(P=0.021) (Table 4.7).

Table 4.7. Effect of seasons at three P levels on the number of nodules plant^{-1} in groundnut

P x season	**Number of nodules plant^{-1}**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	12.9^{d}	13.0^{d}	16.1^{c}	14.0
P20	18.9^{b}	18.4^{b}	18.3^{b}	18.5
P40	22.7^{a}	21.6^{a}	23.0^{a}	22.4
Mean	**18.2**	**17.7**	**19.1**	**18.3**
% CV	**11.3**			
P x season $LSD_{0.05}$	**1.7**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

The number of nodules plant^{-1} in the first 10 cm at 10 weeks after planting in groundnut was affected by intercropping (P=0.0001) (Table 4.6). Sole groundnut and sweetpotato- groundnut intercropping had a significantly higher groundnut number of nodules plant compared to sweetpotato- soybean and sweetpotato- groundnut- soybean intercropping system (P=0.0001) (Fig 4.3).



SP-SB-GN-sweetpotato-soybean-groundnut, SB-GN-sweetpotato-groundnut, Sole GN-sole groundnut, SP-GN-sweetpotato-groundnut.
Bars indicated with the same letter do not differ significantly at P=0.05.

Figure 4.3. Effect of intercropping on the number of nodules plant in groundnut at Umbeluzi research station during 2013/14, 2014/15 and 2015/16 growing season.

4.3.8 Number of days to first flowering in groundnut

Groundnut number of days to first flowering in was affected by P levels (P=0.0001). There was significantly fewer days to first flowering in groundnut at 20 and 40 kg P ha^{-1} than 0 kg P ha^{-1} (P=0.0001) (Fig 4.4)

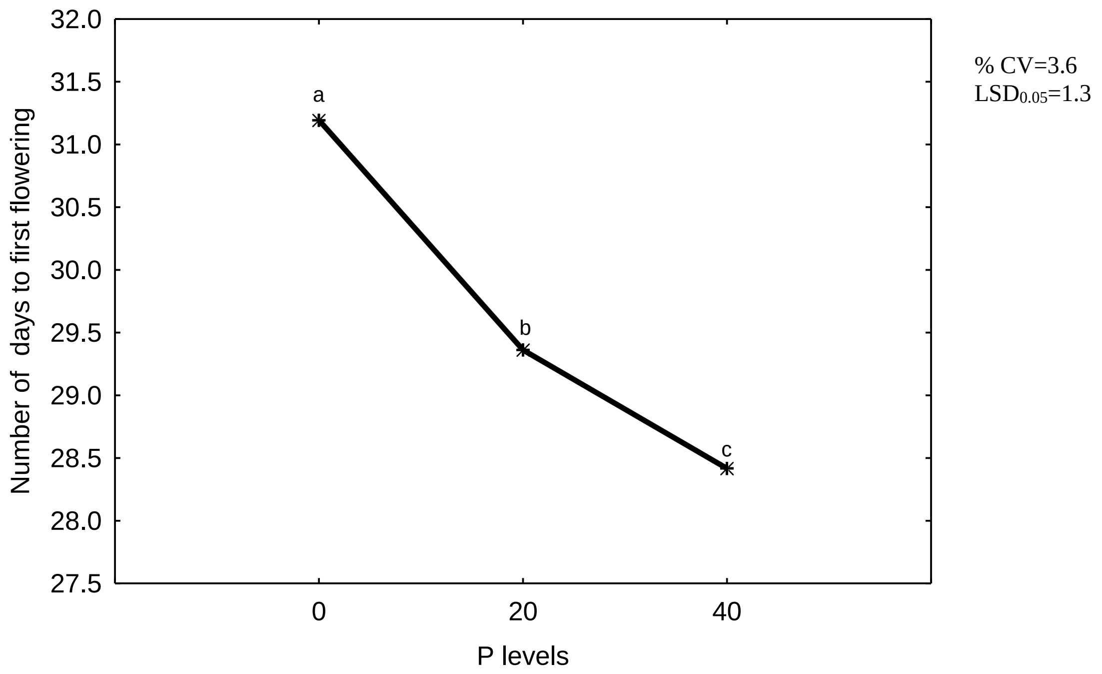


Figure 4.4 Effect of P on the number of days to first flowering in groundnut.

Intercropping x season interaction was significant for the number of days to first flowering (P=0.0001) in groundnut (Table 4.6). Sweetpotato- groundnut- soybean intercropping and soybean- groundnut intercropping had a significantly higher number of days to first flowering in groundnut than in sole groundnut cropping system (P=0.0001) in the 2013/14 and 2014/15 growing seasons but not in the 2015/16 growing season (P=0.0001) (Table 4.8).

Table 4.8. Effect of intercropping sweetpotato, groundnut and soybean on groundnut number of days to first flowering and groundnut number of leaves plant^{-1} of groundnut during 2013/14, 2014/15 and 2015/16 growing seasons

Intercropping x season	**Groundnut number of days to first flowering**				**Ground number of leaves plant^{-1}**			
	Growing seasons				**Growing seasons**			
Intercropping	**2013/14**	**2014/15**	**2015/16**	**Mean**	**2013/14**	**2014/15**	**2015/16**	**Mean**
Sole groundnut	27.0^{e}	28.7^{c}	29.1^{c}	**28.3**	159.4^{f}	166.3^{bcd}	168.7^{bcd}	**164.8**
Sweetpotato- groundnut	27.4^{de}	29.2^{c}	28.2^{cd}	**28.3**	174.6^{a}	170.8^{ab}	169.7^{abc}	**171.7**
Soybean- groundnut	32.0^{a}	32.1^{a}	31.0^{ab}	**31.7**	160.8^{ef}	146.1^{g}	158.7^{f}	**155.2**
Sweetpotato- groundnut- soybean	32.9^{a}	30.3^{b}	28.9^{c}	**30.7**	165.6^{cde}	163.8^{de}	164.9^{cde}	**164.8**
Mean	**29.8**	**30.1**	**29.3**	**29.3**	**165.1**	**161.8**	**165.5**	**164.1**
% CV	**3.6**				**3.3**			
Intercropping x seasons LSD $_{0.05}$	**1.0**				**5.0**			

For each parameter, means with at least a common letter are not significantly different, $LSD_{0.05}$

4.3.9 Number of groundnut leaves plant^{-1}

Sole groundnut had a significantly higher number of leaves plant^{-1} than in soybean- groundnut intercropping in the 2014/15 and 2015/16 growing seasons but not significantly different in the 2013/14 growing season (P=0.0001) (Table 4.8). Intercropping x season interaction was significant for the number of groundnut leaves plant^{-1} (P=0.0001) (Table 4.6).

4.3.10 Vegetative growth parameters of soybean

Summary of ANOVA and F values for the soybean vegetative growth parameters measured are shown in Table 4.7. Table 4.9 show that intercropping x P interaction significantly affected soybean number of nodules in the first 10 cm and soybean stem diameter (cm). Intercropping x P x season interaction had no significant effects on the measured soybean growth parameters (Table 4.9).

Table 4.9. Summary of significant effects (F- values) from the analysis of variance done on soybean growth parameters measured at Umbeluzi research station in Mozambique in 2013/14, 2014/15 and 2015/16 growing seasons

Source of variation	Soybean plant height (cm)	Soybean number of nodules in the first 10 cm	Soybean stem diameter (cm)
I	***	ns	*
P	***	***	***
S	**	***	***
I x P	ns	*	*
I x S	ns	ns	ns
P x S	*	*	***
I x P x S	ns	ns	ns

*, **, *** denote significance at P≤0.05, P≤0.01, P≤0.001 respectively and ns denotes non significance at P≤0.05.

I-intercropping, P-phosphorus S- season, I x P-intercropping x Phosphorus, I x S-intercropping x season, I xP x S-intercropping x Phosphorus x season interaction.

4.3.11 Plant height in soybean

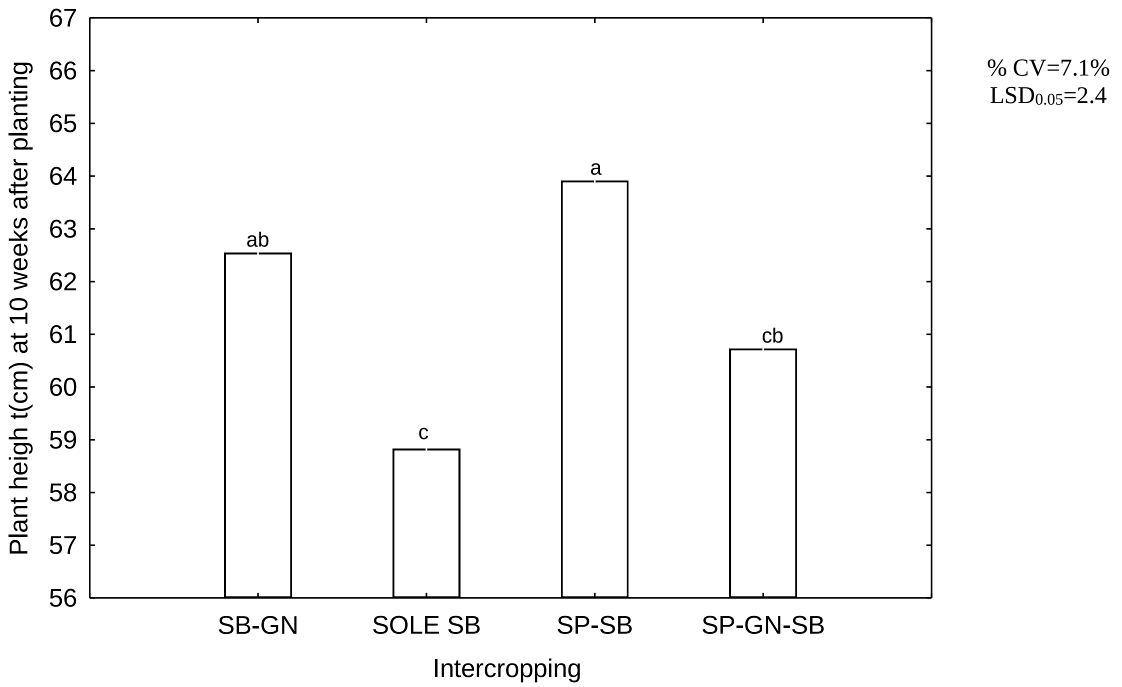
In the 2013/14 growing season, soybean plant height was significantly higher than in the 2014/15 growing season at 0 kg P ha^{-1} but not at the other P levels. At 20 kg P ha^{-1} however, soybean plant height in the 2015/16 growing season was significantly higher than in the 2013/14 growing season. (Table 4.10). P x season interaction was significant for soybean plant height (P=0.048) (Table 4.9).

Table 4.10. Effect of P on soybean plant height during the 2013/14, 2014/15 and 2015/16 growing seasons at Umbeluzi research station.

P x season	**Soybean plant height (cm)**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	55.3^{c}	50.5^{d}	52.6^{cd}	**52.8**
P20	64.3^{b}	65.4^{ab}	68.4^{a}	**66.0**
P40	65.1^{ab}	63.5^{b}	68.5^{a}	**65.7**
Mean	**61.6**	**59.8**	**63.2**	**61.5**
% CV	**7.1**			
P x season LSD$_{0.05}$	**3.6**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

Main effects of intercropping were significant for soybean plant height (P=0.005) (Table 4.9). Sweetpotato- soybean and groundnut- soybean had a significantly higher soybean plant height than sole soybean (P=0.005) (Fig 4.5)



SB-GN-sweetpotato-groundnut, SOLE SB-sole soybean, SP-SB-sweetpotato-soybean, SP -GN-SB -sweetpotato -groundnut-soybean.
Lines indicated with the same letter do not differ significantly at P=0.05.

Figure 4.5. Effect of intercropping on soybean plant height.

4.3.12 Number of nodules plant^{-1} in soybean

Intercropping x P interaction was significant for soybean number of nodules plant^{-1} (P=0.034) (Table 4.9). Number of nodules plant^{-1} in soybean was significantly higher at 40 kg P ha^{-1} than 0 kg P ha^{-1} in all intercropping combinations and sole soybean crop (P=0.034) (Table 4.11). There was a significantly higher number of nodules plant^{-1} at 40 kg P ha^{-1} than 20 kg P ha^{-1} on groundnut- soybean, sweetpotato- groundnut- soybean intercropping and sole soybean (P=0.034) (Table 4.11).

The number of nodules plant^{-1} was significantly higher at 20 kg P ha^{-1} than at 0 kg P ha^{-1} in the 2013/14 and 2015/16 growing season but not in the 2014/15 growing season (P=0.025) (Table 4.12). There was a significantly higher number of nodules plant^{-1}at 40 kg P ha^{-1} than at 20 kg P ha^{-1} in the 2014/15 and 2015/16 growing seasons but not in 2013/14 growing season (P=0.025) (Table 4.12). Phosphorus x season interaction was significant for number of nodules plant^{-1} in soybean (P=0.025) (Table 4.9).

Table 4.11. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on the number of nodules plant^{-1} in soybean at Umbeluzi research station

Intercropping x P	**Number of nodules plant^{-1}**			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole soybean	16.0^{c}	17.2^{bc}	20.9^{a}	**18.0**
Groundnut- soybean	13.1^{d}	18.0^{abc}	22.1^{a}	**17.7**
Sweetpotato- soybean	16.9^{c}	19.7^{ab}	21.2^{a}	**19.3**
Sweetpotato-groundnut- soybean	16.1	15.3^{cd}	20.3^{a}	**17.2**
Mean	**15.5**	**17.6**	**21.1**	**18.1**
% CV	**15.6**			
Intercropping x P LSD$_{0.05}$	**2.6**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

Table 4.12. Effect of P on soybean number of nodules plant^{-1} over three season at Umbeluzi research station in Mozambique

P x season	**Soybean number of nodules plant^{-1}**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	15.0^{d}	17.6^{c}	14.3^{d}	**15.6**
P20	17.5^{c}	17.5^{c}	17.7^{c}	**17.6**
P40	19.0^{bc}	24.3^{a}	20.1^{b}	**21.1**
Mean	**17.2**	**19.8**	**17.4**	**18.1**
% CV	**15.6**			
P x season LSD$_{0.05}$	**2.3**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

4.3.13 Stem diameter in soybean

Intercropping x P interaction was significant for stem diameter in soybean (P=0.049) (Table 4.9). Groundnut- soybean intercropping had a significantly higher soybean stem diameter at 0 kg P ha^{-1} than sole soybean but the two cropping systems had no significant difference at 20 and 40 kg P ha^{-1} (P=0.049) (Table 4.13). Groundnut- soybean intercropping at 0 and 20 kg P ha^{-1} had a significantly higher soybean stem diameter than sweetpotato- soybean intercropping but at 40 kg P ha^{-1} there was no significant difference between the two intercropping systems. (P=0.049) (Table 4.13). Sole soybean at 0 and 20 kg P ha^{-1} had a significantly higher soybean stem diameter than in sweetpotato- soybean intercropping but there was no significant difference between them at 40 kg P ha^{-1} (P=0.049) (Table 4.13).

Table 4.13. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on soybean stem diameter.

Intercropping x P	Stem diameter (cm)			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole soybean	0.6^{fg}	0.69^{c}	0.72^{ab}	**0.67**
Groundnut- soybean	0.64^{de}	0.71^{bc}	0.73^{ab}	**0.69**
Sweetpotato- soybean	0.59^{g}	0.66^{d}	0.74^{a}	**0.66**
Sweetpotato-groundnut- soybean	0.62^{ef}	0.69^{c}	0.71^{bc}	**0.67**
Mean	**0.61**	**0.69**	**0.73**	**0.68**
% CV	3.5			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

Phosphorus x seasons interaction was significant for soybean stem diameter (P=0.000) (Table 4.9). There was a significantly higher soybean stem diameter at 0 kg P ha^{-1} in the 2015/16 than 2013/14 and 2014/15 but there was no significant difference in soybean stem diameter between the 2013/14 and 2014/15 growing seasons at 0 kg P ha^{-1} (P=0.0001) (Table 4.14). On average there was a 11.3 % increase in soybean stem diameter by increasing P application from 0 kg P ha^{-1} to 20 kg P ha^{-1} (Table 4.14). Stem diameter was significantly higher at 40 kg P ha^{-1} than at 20 kg ha^{-1} in the 2013/14 and 2014/15 and not in 2015/16 growing seasons (P=0.0001) (Table 4.14).

Table 4.14. Effect of P on soybean stem diameter over three seasons

P x season	Soybean stem diameter (cm)			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	0.58^{g}	0.58^{g}	0.69^{de}	**0.62**
P20	0.64^{f}	0.67^{e}	0.76^{a}	**0.69**
P40	0.71^{cd}	0.74^{ab}	0.73^{bc}	**0.73**
Mean	**0.64**	**0.66**	**0.73**	**0.68**
% CV	3.5			
P x season $LSD_{0.05}$	**0.02**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

4. 4 Discussion

Intercropping and P application was beneficial in increasing number of leaves plant^{-1} in sweetpotato as observed in this study. In all intercropping treatments, P application at 20 and

40 kg ha^{-1} resulted in a higher number of leaves $plant^{-1}$ than at 0 kg P ha^{-1}. This could be attributed to the positive effects of intercropping on N fixation of the legume component and consequently on number of leaves $plant^{-1}$ in sweetpotato. These results are important for improved capture of solar radiation for photosynthesis and hence improved sweetpotato yields. In addition the results are significant for farmers who produce sweetpotatoes for consumption of the storage root and leaves as vegetables especially in Maputo, Inhambane, Gaza, Manica and Sofala provinces in Mozambique. Thus application of P fertiliser and sweetpotato- legume intercropping may increase sweetpotato leaves and hence improve the farmers' income through leaf sales, food and nutritional security in these regions. The observed increase in the number of leaves $plant^{-1}$ may be due to the beneficial effect of P on the activation of photosynthesis and metabolic processes of organic compounds in plants, thus, encouraging plant growth (Abdel-Razzak et al. 2013). These results are in accordance with work by Hassan_et al. (2005) and El-Sayed et al. (2011), who found that application of 45 kg P_2O_5 ha^{-1} to sweetpotato plants significantly increased number of leaves $plant^{-1}$ and other growth parameters compared to 0 kg P ha^{-1}.

Sweetpotato- soybean intercropping at 20 kg ha^{-1} resulted in higher main stem length of sweetpotato than in sole sweetpotato. This result was probably because of competition for light between these two component crops. Njoku et al. (2007) had noted that canopy height is one of the important features that determine competition ability of plants for light. Mean sweetpotato main stem length was higher at 20 kg P ha^{-1} than at 0 kg P ha^{-1} indicating that fertiliser P was essential for stem elongation. However, higher P levels beyond 20 kg P ha^{-1} did not promote main stem growth. This is in consonance with the finding of Kareem (2013) that higher level of phosphorus application produce shorter vines. The stems are used as planting material in sweetpotato production. Therefore the results of this study are significant for vine multipliers especially decentralised vine multipliers in Mozambique who may want to produce long stems used as planting material through sweetpotato-soybean intercropping with P fertilizer application. However, there is need to investigate further the vigour of the long stems which suffer a lot from heavy shading under the sweetpotato- soybean intercropping system.

Fresh root mass plant^{-1} was higher at 20 and 40 kg P ha^{-1} than at 0 kg P ha^{-1} in all intercropping combinations. This indicates that P fertiliser application is essential for metabolic process such as respiration that culminates in root growth. Long roots and high root surface enable the plant to scavenge for nutrients especially P that is relatively immobile in the soil thereby providing a plant with a competitive edge for soil nutrients and water (Rashid and Waithaka 2009). The results are in line with work by Hassan et al. *(*2005) who observed that P-fertilizer application positively increase root mass and sweetpotato productivity. Sweetpotato farmers are recommended to apply P fertiliser at 20-40 kg for establishment of fibrous root mass although 20 kg P ha^{-1} has more advantages such as highest yield that was demonstrated in chapter 5 of this thesis. Rapid groundcover by sweetpotato- groundnut intercropping at 40 kg P ha^{-1} probably promoted moisture conservation that resulted in dissolution of P and hence allowed its take up by component plants culminating in gain in root fresh mass compared to sole sweetpotato.

Sweetpotato stem diameter was higher on sweetpotato- groundnut intercropping and sole crop than on sweetpotato- soybean intercropping. This result could have been caused by the use of assimilates for stem elongation by sweetpotato in sweetpotato- soybean intercropping in a bid to compete for sunlight at the expense of increasing stem diameter.

In the groundnut crop, increase in P from 0 kg ha^{-1} to 40 kg ha^{-1} increased the number of nodules plant^{-1}. This indicates that phosphorus is important for increased nodulation. Similar results were observed by Ojo et al. (2016) who noted that phosphorus at 40 kg ha $^{-1}$ has beneficial effects on nodulation and nitrogen fixation capacity. The nodulation at 40 kg P ha^{-1}

may have contributed to an increase in N fixation that resulted in higher total N content of plots containing sweetpotato- soybean intercropping shown in Chapter 3 of this thesis.

The shading effect of groundnut by soybean in the intercropping system involving soybean in the current study could have probably prolonged flowering initiation in the groundnut crop as observed in the 2013/14 and 2014/15 growing seasons. Saifuddin et al (2010) reported similar results in which flowering days of Bougainvillea *glabra* increased from 15 to 25 with an increase of shading from 0 to 30 %. Farmers are therefore recommended to intercrop groundnut with a component crop of the same height to minimise shading effects that may culminate in delay in flowering.

Soybean depressed groundnut number of leaves plant^{-1} in soybean- groundnut intercropping probably due to shading effect that could probably have accelerated senescence of groundnut leaves. Leaves are important sources where physiological process such as photosynthesis takes place. Interference with leaf development is undesirable for photosynthesis and therefore soybean-groundnut intercropping should be discouraged. The results are similar to that of Wahua and Millen (1998) who reported that heavy shading of cowpea by intercropped maize at anthesis accelerated leaf senescence resulting in losses of lower leaves from the legumes.

Application of 20 kg P ha^{-1} promoted soybean plant height compared to 0 kg P ha^{-1}. Plant height is a morphological attribute that allow plants to fully exploit solar radiation for photosynthesis. The results could be attributed to positive effects of P on biochemical processes such as photosynthesis, nodulation and N fixation resulting in increased soybean growth. The findings are in partial agreement with the results by Akter et al. (2013) who reported highest plant height at 50 kg P ha^{-1} in soybean in Bangladesh. Bothe et al. (2000) also reported that P application at 75 kg ha^{-1} enhanced soybean plant height.

Number of nodules plant^{-1} in soybean was more at 40 kg P ha^{-1} compared to 0 kg P ha^{-1} in all treatments. The result of the present study show that P is an important nutrient for legumes involved in the conversion of atmospheric N (N_2) into an ammonium (NH_4) form useable by plants. Farmers may increase nodulation and hence N fixation through P application in the soybean crop.

Increasing P application from 0 to 20 kg P ha^{-1} increased stem diameter in soybean in all the growing seasons. An increase in P levels probably resulted in an increase in vascular bundles and more thick walled cells that consequently increased the stem diameter in soybean. Sarker et al. (2010) working with maize observed that under P deficiency, vascular bundles become smaller in size, with smaller thick walled cells resulting in small stem diameter compared to treatment with adequate P in maize.

4. 5 Conclusion

It is concluded that P application at 20 kg ha^{-1} and intercropping appeared beneficial in improving vegetative growth of the component crops in the cropping system. Farmers may benefit from increased sweetpotato leaves for vegetable and increased root fresh mass through sweetpotato- groundnut intercropping at 20 kg P ha^{-1} in order to increase the plant's ability to scavenge for nutrients in the soil. However, for vine production sweetpotato- soybean intercropping at 20 kg ha^{-1} maybe the better option by farmers since the study showed that sweetpotato– soybean intercropping had a significantly higher main stem length in sweetpotato than sole sweetpotato.

Sweetpotato and groundnut complement each other well and their intercropping should be encouraged and soybean intercropping discouraged except maybe for vine production although the issue of vigour of the lighter vines still require further investigation before a conclusive recommendation.

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Chapter 5 : Effects of intercropping sweetpotato (*Ipomoea batatas* (L) Lam) with groundnut (*Arachis hypogea L.*) and soybean (*Glycine max* L.) at three phosphorus (P) levels on yield and yield components of sweetpotato, groundnut and soybean.

Abstract

Sweetpotato is among the most important root crops grown in Mozambique. However, the yield obtained among smallholder farmers is lower than its genetic potential. The objective of the study was to investigate the effect of intercropping sweetpotato with groundnut and soybean at three P levels on yield and yield components of sweetpotato, groundnut and soybean at Umbeluzi research station during the 2013/14, 2014/15 and 2015/16 growing seasons. Main plot treatments were sole sweetpotato, sole groundnut, sole soybean, sweetpotato-groundnut, sweetpotato-soybean, sweetpotato- groundnut- soybean, groundnut- soybean intercropping. The subplot treatments were 0, 20 and 40 kg P ha^{-1} applied at planting. Sweetpotato- groundnut intercropping at 0 and 20 kg P ha^{-1} had 32.7 % and 58.5 % more total storage root yield respectively compared to sole sweetpotato. There was no significant increase in total storage root yield between 20 kg P ha^{-1} and 40 kg P ha^{-1} for sweetpotato- groundnut, sweetpotato-soybean intercropping systems and sole sweetpotato. There was a mean total storage root yield increase of 25.4 % at 20 kg P ha^{-1} compared to at 0 kg P ha^{-1}. Sweetpotato-groundnut intercropping increased commercial root yield compared to sole sweetpotato. Commercial root yield was 48.3 % higher in sweetpotato- groundnut intercropping compared to sole sweetpotato at 20 kg P ha^{-1}. Sole sweetpotato at 40 kg P ha^{-1} had higher vine yield compared to sweetpotato-groundnut and sweetpotato- groundnut- soybean intercropping in the 2013/14 and 2014/15 growing seasons. Sweetpotato- groundnut intercropping at 20 kg P ha^{-1} had 27.4 % higher number of storage roots plant^{-1} compared to sole sweetpotato. Sweetpotato- soybean intercropping decreased number of storage roots plant^{-1} compared to sole sweetpotato in the 2014/15 growing season. There was no significant difference in the number of storage roots plant^{-1} between sweetpotato- groundnut intercropping and sole sweetpotato in all growing

seasons. Sole sweetpotato at 20 kg P ha^{-1} increased storage root diameter compared to sweetpotato- soybean intercropping. Sweetpotato- soybean intercropping increased storage root length at 20 kg P ha^{-1} compared to 0 kg P ha^{-1} in the 2013/14 and 2015/16 growing seasons. Total biomass at 20 kg P ha^{-1} was higher than at 0 kg P ha^{-1}in all treatments. Sweetpotato–groundnut and sweetpotato- groundnut- soybean intercropping had a significantly higher sweetpotato partial LER than sole sweetpotato at all P levels. Groundnut pod yield and number of pods plant^{-1} was significantly higher in sole groundnut than in groundnut-soybean intercropping at 20 kg P ha^{-1}. There was a 62.5 %, 51.7 % and 38.7 % increase in soybean pod yield by increasing P from 0 to 40 kg ha^{-1} in soybean- groundnut, sweetpotato- soybean and sweetpotato- groundnut- soybean intercropping respectively.

The results suggest that intercropping sweetpotato with groundnut at 20 kg P ha^{-1} positively influenced productivity of sweetpotato and groundnut. Increasing the P rate beyond 20 kg ha^{-1} did not result in significant increase in sweetpotato yield, therefore it is recommended that farmers intercrop sweetpotato with groundnut at 20 kg P ha^{-1}. However, 40 kg P is better for soybean productivity.

Key words: groundnut, intercropping, soybean, smallholder farmer, sweetpotato.

5.1 Introduction

Due to increasing climatic uncertainty resulting from climate change and declining soil fertility, crop failures often result in food shortages affecting up to 44 % of the people who are reported to be suffering from malnutrition every year in Mozambique (GoM 2008). Rapid population growth has made the traditional systems of soil fertility maintenance through bush-fallow both unpopular and non-feasible (Zingore et al. 2007). The use of animal manure, which has become common since the 1930s, is limited by low nutrient content, due to poor storage and huge quantities required to satisfy crop needs (Shoko et al. 2011). Green manuring and incorporation of crop residues were recommended to improve soil organic matter content but farmers commonly remove crop residues from the field for livestock feed, fencing, roofing and other purposes (Shoko et al. 2011). These factors have contributed to low crop productivity resulting in food insecurity and malnutrition in Mozambique.

Of all cropping systems, crop diversification through intercropping involving legumes with high nitrogen (N) fixing capacity has the greatest potential for maintaining soil fertility at reasonable levels and to improve crop productivity (Shoko et al. 2011). Intercropping Orange fleshed sweetpotato (OFSP) varieties that are drought resistant with soybean and groundnut might be a viable option to improve crop yields and nutrition of children in Mozambique. Intercropping also ensures a reasonable harvest of at least one crop even during bad years. Risk of total crop failure is reduced and assures food security at household level (Walker and Jodha 1986). Intercropping increase plant population density, ground cover and shading effect to weed species thereby suppressing weed growth (Chikoye et al. 2006). Grain legumes can cover their N demand from atmospheric N2 (Hauggaard-Nielsen et al. 2001) and therefore when intercropped with non-legumes such as sweetpotatoes there is less competition for soil mineral N (Dusa and Stan 2013). Intercropping may provide alleviation of hunger and poverty for smallholder families.

Farmers in Mozambique practice intercropping of legumes with sweetpotatoes (*Ipomoea batatas* (L.) Lam.), cassava (*Manihot esculenta* Cranz) or cereals. However, there is scarcity of data on the effects of intercropping sweetpotato with legumes on sweetpotato yield in Mozambique. The objective of this study was to determine the effect of intercropping sweetpotato, groundnut and soybean at three P levels on the yield and yield components of sweetpotato, groundnut and soybean.

5.2 Material and methods

5.2.1 Experimental site

A field experiment was carried out at Umbeluzi research station (26° 03' S and 32° 15 ' E, 12 m. a. s. l.) 25 km from Maputo, Mozambique (Andrade et al. 2016) during the 2013/14, 2014/15 and 2015/16 growing seasons. Umbeluzi has a pronounced dry season from May to October and a wet season from November to March.

5.2.2 Experimental site and design

Experimental site description, location and design is given in section 3.2.3 in Chapter 3 of this thesis.

5.2.3 Yield trait measured

At harvest 50 sweetpotato, 150 soybean and 80 groundnut plants were harvested from each subplot in the middle rows for yield determination. Sweetpotato roots harvested from each net plot were cleaned of all the soil and weighed. Total storage root yield (All storage roots harvested) and vine yield, total biomass (all storage roots, vines and leaves) and commercial root yield (weight of storage roots $\geq$200g, devoid of insect and disease attack as well as harvest injuries) were measured using a balance. Harvest index (%) was calculated using the formula: Total storage root yield/total biomass. Number of storage roots plant^{-1} were determined by randomly selecting 5 plants from the harvested plants in each replicate and counting physically the number of storage roots and calculating the mean. Storage root length and storage root diameter were determined by randomly selecting 5 storage roots from the harvested roots and measured using a Vernier callipers (Kaur 2014) and the mean of the 5 storage roots was calculated from each replicate.

In the groundnut crop, 60 plants were harvested from the net plot and all pods removed from the plant and pod yield was determined by weighing the pods using a balance. From the harvested plants, 5 plants were selected at random and number of pods plant^{-1} was determined through physical counting. Groundnut from the 60 plants from each subplot was shelled and then weighed to determined shelled groundnut yield by weighing the shelled groundnut using a balance.

In soybean, pod yield was determined by harvesting 180 plants from the net plot and measuring the weight using a balance. Five plants were selected from the harvested plants and the number of pods plant^{-1}was physically counted and an average number of pods plant^{-1}was calculated. Soybean pods were randomly selected from harvested pods and shelled until getting 100-seeds. The seeds were then weighed to determine the 100- seed weight on a fresh weight basis using a balance.

5.2.4 Land equivalent ratio (LER)

The land equivalent ratio (LER) was calculated from total storage root yield of sweetpotato, soybean pod yield and groundnut pod yield using the formula described by De Wit and Van Den Bergh, (1965).

$$LER = L_A+L_B+L_C = Y_A/S_A + Y_B/S_B + Y_C/S_C$$

Where L_A, L_B and L_C are partial land equivalent ratios of the three component crops, Y_A is the yield of sweetpotato under intercropping and S_A is the yield of sole sweetpotato, Y_B is the yield of groundnut intercropped and S_B is the yield of sole groundnut, Y_C is the yield of soybean intercropped and S_C is the yield of sole soybean.

5.2.5 Data analysis

All data collected was analysed using Statistica (13.0) software following standard analysis of variance procedures (Gomez and Gomez 1984). Means were separated using Fishers LSD at 5 % probability. Multiple regression was performed using Statistica (13.0) software on total storage root yield as the dependent variable and number of roots plant, vine yield, total biomass and commercial root yield as predictor variables.

5.3 Results
5.3.1 Sweetpotato yield components
5.3.1.1 Significance of F values.

Summary of ANOVA and F values for the sweetpotato yield parameters measured are shown in Table 5.1. Table 5.1 show that intercropping x P x season interaction significantly affected sweetpotato storage root length, vine yield and percent harvest index. Total storage root yield, commercial root yield and total biomass were significantly affected by intercropping x P, intercropping x season and P x season interaction interactions (Table 5.1).

Table 5.1. Summary of significant effects (F- values) from the analysis of variance done on sweetpotato yield parameters measured at Umbeluzi research station in Mozambique in 2013/14, 2014/15 and 2015/16 growing seasons

Source	Total storage root yield (t ha^{-1})	Number of storage roots plant^{-1}	Commercial root yield (t ha^{-1})	Total biomass yield (t ha^{-1})	Storage root diameter (cm)	Storage root length (cm)	Vine yield (t ha^{-1})	Percent harvest index
I	***	*	***	***	***	ns	***	***
P	***	***	***	***	ns	***	***	***
S	***	*	***	***	ns	***	***	***
I x P	***	***	***	***	*	ns	***	***
I x S	*	***	*	***	ns	***	***	***
P x S	***	ns	***	***	ns	***	***	ns
I x P x S	ns	ns	ns	ns	ns	*	***	*

*, *** Significant at P≤0.05, P≤0.001 respectively, ns denotes non significance at P≤0.05.
I-Intercropping, P-Phosphorus, S- seasons, I x P-Intercropping x seasons, I x S-Intercropping x season, P x S-Phosphorus x season, I x P x S-Intercropping x Phosphorus x season

5.3.1.2 Total storage root yield

Sweetpotato- groundnut- soybean intercropping had a significantly higher storage root yield at 0 and 20 kg P ha^{-1} than sole sweetpotato but there was no significant difference between the two cropping systems at 40 kg P ha^{-1}(P<0.001) (Table 5.2). Sweetpotato- groundnut and sweetpotato- groundnut- soybean intercropping had no significant difference in total storage root yield at 0 and 20 kg P ha^{-1} but sweetpotato- groundnut intercropping had a significantly higher total storage root yield than sweetpotato- soybean- groundnut intercropping at 40 kg P ha^{-1} (P<0.001) (Table 5.2). Sweetpotato- groundnut, sweetpotato- soybean and sweetpotato- groundnut- soybean intercropping had a significantly higher total storage root yield at 20 kg P ha $^{-1}$ than at 0 kg P ha^{-1} but not with sole sweetpotato (P<0.001) (Table 5.2). Sweetpotato- groundnut intercropping had a significantly higher storage root yield than sole sweetpotato at all P levels (P<0.001) (Table 5.2). Sweetpotato- groundnut intercropping resulted in 58.5 % more storage root yield compared to sole sweetpotato at 20 kg P ha^{-1}. In addition, sweetpotato- groundnut, sweetpotato- soybean and sweetpotato- groundnut- soybean intercropping had 33.6 %, 33.6 % and 21.6 % more total storage root yield at 20 kg P ha^{-1} than at 0 kg P ha^{-1} respectively (Table 5.2). There was no significant increase in total storage roots between 20 kg P ha^{-1} and 40 kg P ha^{-1} for sweetpotato- groundnut and sole sweetpotato (P>0.05) (Table 5.2).

Table 5.2. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on the sweetpotato total storage root yield at Umbeluzi research station

Intercropping x P	**Total storage root yield (t ha^{-1})**			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole sweetpotato	11.0^{e}	12.3^{de}	13.8^{cd}	**12.4**
Sweetpotato-groundnut	14.6^{c}	19.5^{ab}	20.6^{a}	**18.2**
Sweetpotato-soybean	11.6^{de}	15.5^{c}	13.5^{cd}	**13.5**
Sweetpotato- groundnut- soybean	14.8^{c}	18.0^{b}	15.0^{c}	**16.0**
Mean	**13.0**	**16.3**	**15.7**	**15.1**
% CV	**14.5**			
Intercropping x P LSD$_{0.05}$	**2.0**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

Total storage root yield was significantly lower in sole sweetpotato than sweetpotato- soybean in the 2013/14 but the two had no significant difference in 2014/15 and 2015/16 growing seasons (P=0.027) (Table 5.3). Sweetpotato- groundnut intercropping had a significantly higher storage root yield than sweetpotato- groundnut- soybean intercropping in 2013/14 and 2015/16 but the two cropping systems had no significant difference in the 2014/15 (P=0.027) (Table 5.3). In 2015/16 growing season alone, sweetpotato- groundnut intercropping resulted in 14.6 % more total storage root yield than in sweetpotato- groundnut-soybean intercropping. Intercropping x season interaction was significant for total storage root yield (P=0.027) (Table 5.1).

Table 5.3. Effect of intercropping sweetpotato, groundnut and soybean over three growing seasons

Intercropping x season	**Total storage root yield (t ha^{-1})**			
	Growing seasons			
Intercropping	**2013/14**	**2014/15**	**2015/16**	**Mean**
Sole sweetpotato	9.8^{e}	9.7^{e}	17.5^{c}	**12.3**
Sweetpotato-groundnut	17.3^{c}	13.0^{d}	24.4^{a}	**18.2**
Sweetpotato-soybean	13.1^{d}	9.4^{e}	18.2^{c}	**13.6**
Sweetpotato- groundnut- soybean	13.8^{d}	12.7^{d}	21.3^{b}	**15.9**
Mean	**13.5**	**11.2**	**20.4**	**15.0**
% CV	**14.5**			
Intercropping x season LSD $_{0.05}$	**2.0**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

There was a significantly higher total storage root yield in 2015/16 than 2013/14 and 2014/15 growing seasons at all P levels (P=0.028) (Table 5.4). There was a significantly higher total storage root yield at 20 kg P ha^{-1} than at 0 kg P ha^{-1} in 2013/14 and 2015/16 growing seasons but not in the 2014/15 growing season (P=0.028) (Table 5.4). On average, increasing P application from 0 to 20 kg ha^{-1} increased total storage root yield by 25.4 % (Table 5.4). There was no significant increase in total storage root yield between 20 kg P ha^{-1} and 40 kg P ha^{-1} in all the growing seasons (P>0.05) (Table 5.4). Phosphorus (P) x season interaction was significant for total storage root yield (P=0.028) (Table 5.1).

Table 5.4. Effect of P on sweetpotato total storage root yield over three growing seasons

P x season	**Total storage root yield (t ha^{-1})**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	11.7^{d}	10.6^{d}	16.7^{b}	13.0
P20	14.6^{c}	11.9^{d}	22.5^{a}	16.3
P40	14.2^{c}	11.1^{d}	21.9^{a}	15.7
Mean	**13.5**	**11.2**	**20.4**	**15.0**
% CV	**14.5**			
P x seasons LSD$_{0.05}$	**1.8**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

5.3.1.3 Commercial storage root yield

Sweetpotato-soybean at 20 kg P ha^{-1} had a significantly higher commercial root yield than sole sweetpotato but the two cropping systems had no significant difference at 0 and 40 kg P ha^{-1} (P=0.00011) (Table 5.5). Sweetpotato- groundnut- soybean intercropping had a significantly higher commercial root yield than sole sweetpotato at 0 and 20 kg P ha^{-1} but the two cropping systems had no significant difference at 40 kg P ha^{-1} (P=0.00011) (Table 5.5). Sweetpotato-groundnut and sweetpotato- groundnut- soybean intercropping had a significantly higher commercial storage root yield than sole sweetpotato cropping system (P=0.0001) at 0 kg P ha^{-1} and 20 kg P ha^{-1} (Table 5.5). Sweetpotato- groundnut intercropping had a significantly higher commercial root yield than sole sweetpotato at all P levels (P=0.00011) (Table 5.5) There was a 22.9 % and 48.3 % higher commercial root yield in sweetpotato- groundnut intercropping at 0 and 20 kg P ha^{-1} respectively compared to sole sweetpotato (Table 5.5). Intercropping x P interaction was significant for sweetpotato commercial storage root yield (P=0.00011) (Table 5.1).

Table 5.5. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on sweetpotato commercial root yield at Umbeluzi research station

Intercropping x P	**Commercial storage root yield (t ha^{-1})**			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole sweetpotato	10.5^{d}	11.8^{cd}	12.6^{bc}	**11.6**
Sweetpotato-groundnut	12.9^{bc}	17.5^{a}	19.0^{a}	**16.5**
Sweetpotato-soybean	10.6^{d}	13.9^{b}	12.1^{bcd}	**12.2**
Sweetpotato- groundnut- soybean	13.4^{bc}	17.7^{a}	13.5^{bc}	**14.9**
Mean	**11.8**	**15.2**	**14.3**	**13.8**
% CV	**15.1**			
Intercropping x P LSD$_{0.05}$	**1.9**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

Sweetpotato- groundnut intercropping had a significantly higher commercial root yield than sole sweetpotato in all growing seasons (P=0.036) (Table 5.6). Commercial root yield in sweetpotato - groundnut- soybean intercropping was not significantly higher than sweetpotato-soybean in the 2013/14 but was in the other two growing seasons (P=0.036) (Table 5.6).

Sweetpotato- groundnut and sweetpotato- soybean intercropping, in the 2014/15 was significantly lower than in the 2013/14 but not in sweetpotato grown alone or sweetpotato- soybean- groundnut intercropping (P=0.036) (Table 5.6). Sweetpotato- groundnut and sweetpotato- groundnut- soybean intercropping had significantly higher commercial root yield than sole sweetpotato in all growing seasons (P=0.036) (Table 5.6) . Intercropping x season interaction was significant for commercial root yield (P=0.036) (Table 5.1).

Table 5.6. Effect of intercropping sweetpotato, groundnut and soybean over three growing seasons at Umbeluzi research station

Intercropping x season	**Commercial storage root yield (t ha^{-1})**			
	Growing seasons			
Intercropping	**2013/14**	**2014/15**	**2015/16**	**Mean**
Sole sweetpotato	9.2^{e}	9.4^{e}	16.2^{c}	**11.6**
Sweetpotato-groundnut	15.2^{c}	11.7^{d}	22.4^{a}	**16.4**
Sweetpotato-soybean	11.5^{d}	8.9^{e}	16.2^{c}	**12.2**
Sweetpotato- groundnut- soybean	12.5^{d}	12.8^{d}	19.2^{b}	**14.8**
Mean	**12.1**	**10.7**	**18.5**	**13.8**
% CV	**15.1**			
Intercropping x season LSD $_{0.05}$	**1.9**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

Commercial storage root yield was significantly higher at 20 and 40 kg P ha^{-1} than at 0 kg P ha^{-1} (P=0.004) in the 2013/14 and 2015/16 growing seasons (P=0.004) (Table 5.7). There was no significant difference in commercial storage root yield between 20 and 40 kg P ha^{-1} in the 2013/14 and 2015/16 growing seasons (P>0.05) but there was a significantly higher commercial storage root yield at 20 than at 40 kg P ha^{-1} in the 2014/15 growing season (Table 5.7).

Table 5.7. Effect of P on commercial root yield over three growing seasons at Umbeluzi research station

P x season	**Commercial storage root yield (t ha^{-1})**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	10.4^{cd}	10.2^{cd}	15.0^{b}	**11.9**
P20	12.8^{c}	11.9^{c}	21.0^{a}	**15.2**
P40	13.2^{c}	10.1^{d}	19.6^{a}	**14.3**
Mean	**12.1**	**10.7**	**18.5**	**13.8**
% CV	**15.1**			
P x seasons LSD$_{0.05}$	**1.7**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

In 2015/16 growing season, there was a 40 % commercial root yield increase by increasing P level from 0 to 20 kg P ha^{-1} (Table 5.7). Phosphorus x season interaction was significant for sweetpotato commercial root yield (P=0.004) (Table 5.1).

5.3.1.4 Number of storage roots plant^{-1}

Sweetpotato- soybean intercropping and sole sweetpotato at 0 and 20 kg P ha^{-1} had no significant difference in the number of storage roots plant^{-1} but sole sweetpotato had a significantly higher number of roots plant^{-1} than sweetpotato- soybean intercropping at 40 kg P ha^{-1} (P=0.001) (Table 5.8). Sole sweetpotato at 40 kg P ha^{-1} had a significantly higher number of storage roots plant^{-1} than sweetpotato- groundnut- soybean but at 0 and 20 kg P ha^{-1} the two cropping systems had no significant difference in the number of storage roots plant^{-1} (P=0.001) (Table 5.8). Sweetpotato- groundnut intercropping and sole sweetpotato at 0 kg P ha^{-1} had no significant difference in the number of storage roots plant^{-1} but at 20 kg P ha^{-1} sweetpotato- groundnut intercropping had a significantly higher number of storage roots plant^{-1} than sole sweetpotato (P=0.001) (Table 5.8).

Table 5.8. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on the number of sweetpotato storage roots plant^{-1} at Umbeluzi research station

Intercropping x P	Number of storage roots plant^{-1}			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole sweetpotato	5.2^{bcd}	6.2^{bc}	7.4^{ab}	**6.3**
Sweetpotato-groundnut	4.9^{d}	7.9^{a}	5.4^{cd}	**6.1**
Sweetpotato-soybean	5.1^{cd}	6.3^{b}	4.8^{d}	**5.4**
Sweetpotato- groundnut- soybean	5.4^{bcd}	6.3^{b}	5.0^{cd}	**5.6**
Mean	**5.2**	**6.7**	**5.7**	**5.8**
% CV	**20.6**			
Intercropping x P LSD$_{0.05}$	**1.1**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

Application of P at 20 kg P ha^{-1} resulted in 27.4 % increase the number of storage roots plant^{-1} in sweetpotato- groundnut intercropping compared to sole sweetpotato cropping system. There was a significantly higher number of storage roots plant^{-1} at 40 kg P ha^{-1} than at 20 kg P ha^{-1} in sole sweetpotato (Table 5.8). Intercropping x P interaction was significant for number of storage roots plant^{-1} (P=0.001) (Table 5.1).

Sweetpotato- soybean intercropping had 36 % lower number of storage roots plant^{-1} than sole sweetpotato in the 2015/16 growing season (P=0.008) (Table 5.9). There was no significant difference in the number of storage roots plant^{-1} between sweetpotato- groundnut intercropping and sole sweetpotato in all the growing seasons (P>0.05).

Table 5.9. Effect of intercropping sweetpotato, groundnut and soybean on the number of sweetpotato storage roots plant over three seasons

Intercropping x season	**Number of storage roots plant^{-1}**			
	Growing seasons			
Intercropping	**2013/14**	**2014/15**	**2015/16**	**Mean**
Sole sweetpotato	5.7^{abcd}	6.5^{ab}	6.8^{a}	**6.3**
Sweetpotato- groundnut	6.0^{abc}	6.1^{abc}	6.1^{abc}	**6.1**
Sweetpotato- soybean	5.6^{bcd}	5.6^{bcd}	5.0^{cd}	**5.4**
Sweetpotato- groundnut- soybean	4.7^{d}	5.6^{bcd}	6.4^{ab}	**5.6**
Mean	**5.5**	**6.0**	**6.1**	**5.8**
% CV	**20.6**			
Intercropping x season LSD $_{0.05}$	**1.1**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

5.3.1.5 Total biomass

There was a significantly higher total biomass on sweetpotato- groundnut intercropping at 0 and 20 kg P ha^{-1} than sole sweetpotato at the same P levels but the two had no significant difference at 40 kg P ha^{-1} (P=0.0001) (Table 5.10). Sweetpotato- soybean at 0 kg P ha^{-1} had a significantly higher total biomass than sole sweetpotato but at 20 and 40 kg P ha^{-1} there was no significant difference between the two treatments (P=0.0001) (Table 5.10). Sweetpotato- groundnut at 40 kg P ha^{-1} had a significantly higher total biomass than sweetpotato- soybean intercropping but the two intercropping treatments had no significant difference at 0 and 20 kg P ha^{-1} (P=0.0001) (Table 5.10). Sweetpotato- groundnut intercropping at 40 kg P ha^{-1} had a 10.4 % higher total biomass than sweetpotato- soybean intercropping. Sole sweetpotato, sweetpotato- groundnut, sweetpotato- soybean and sweetpotato- groundnut- soybean intercropping had 22.6 %, 10.6 %, 11.6 % and 17.9 % respectively higher total biomass at 20 kg P ha^{-1} compared to at 0 kg P ha^{-1}. Intercropping x P interaction was significant for total biomass (P=0.00011) (Table 5.1).

Table 5.10. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on sweetpotato total biomass at Umbeluzi research station

Intercropping x P	**Total biomass (t ha^{-1})**			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole sweetpotato	30.5^{g}	37.4^{def}	43.6^{ab}	**37.2**
Sweetpotato- groundnut	37.6^{def}	41.6^{bc}	45.7^{a}	**41.6**
Sweetpotato- soybean	35.4^{f}	39.5^{cd}	41.4^{bc}	**38.8**
Sweetpotato- groundnut- soybean	36.3^{ef}	42.8^{ab}	39.3^{cde}	**39.5**
Mean	**35.0**	**40.3**	**42.5**	**39.3**
% CV	**8.2**			
Intercropping x P LSD$_{0.05}$	**3.0**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

Sweetpotato- groundnut intercropping had a significantly higher total biomass in the 2013/14 and 2015/16 growing seasons than sole sweetpotato but there was no significant difference between the two in the 2014/15 growing season (P=0.0001) (Table 5.11). In 2015/16 growing season sweetpotato- groundnut intercropping had 19.3 % higher total above ground biomass than sole sweetpotato. Sweetpotato- soybean intercropping and sole sweetpotato had no significant difference in the 2013/14 and 2014/15 but in the 2015/16 growing season sweetpotato- soybean intercropping had a significantly higher amount of total biomass (P=0.0001) (Table 5.11).

Table 5.11. Effect of intercropping sweetpotato, groundnut and soybean on total biomass yield over three seasons at Umbeluzi research station

Intercropping x season	**Total biomass yield (t ha^{-1})**			
	Growing seasons			
Intercropping	**2013/14**	**2014/15**	**2015/16**	**Mean**
Sole sweetpotato	33.6^{ef}	33.2^{e}	44.5^{c}	**37.1**
Sweetpotato- groundnut	38.6^{d}	33.3^{ef}	53.1^{a}	**41.7**
Sweetpotato- soybean	33.7^{ef}	33.0^{e}	49.5^{b}	**38.7**
Sweetpotato- groundnut- soybean	34.0^{ef}	36.3^{de}	48.1^{b}	**39.5**
Mean	**35.0**	**34.0**	**48.8**	**39.2**
% CV	**8.2**			
Intercropping x season LSD $_{0.05}$	**3.0**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

In 2013/14 and 2015/16 the 20 and 40 kg P ha^{-1} treatments produced significantly more total above ground biomass than the 0 kg P ha^{-1} treatment but in 2014/15 only the 40 kg P ha^{-1} treatment produced more above ground total biomass than the 0 kg P ha^{-1} treatment (P= 0001) (Table 5.12). Phosphorus x season interaction was significant for total biomass (P= 0001) (Table 5.1).

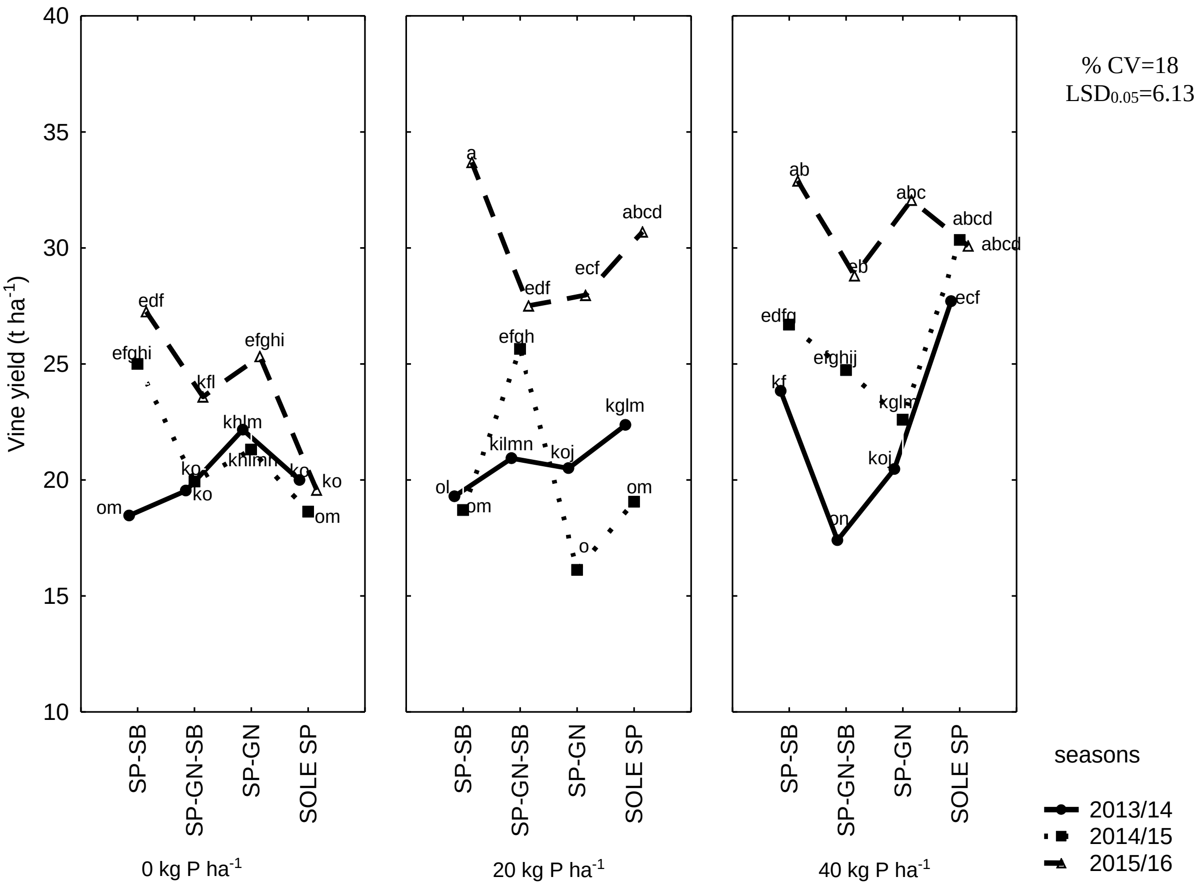
Table 5.12. Effect of P on total biomass yield over three growing seasons at Umbeluzi research station

P x season	**Total biomass yield (t ha^{-1})**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	32.1^{d}	32.0^{d}	40.7^{b}	**35.0**
P20	35.8^{c}	32.5^{d}	52.7^{a}	**40.3**
P40	37.1^{c}	37.4^{c}	53.0^{a}	**42.5**
Mean	**35.0**	**34.0**	**48.8**	**39.2**
% CV	**8.2**			
P x seasons $LSD_{0.05}$	**2.6**			

For each parameter, means with at least a common letter are not significantly different, $LSD_{0.05}$

5.3.1.6 Vine yield

Sweetpotato- soybean intercropping at 0 kg P ha^{-1} had a significantly higher vine yield than sole sweetpotato cropping system in the 2014/15 and 2015/16 growing seasons but not significantly different in the 2013/14 growing season (P=0.021) (Fig 5.1). Intercropping x P x season interaction was significant for vine yield (P=0.021) (Table 5.1).



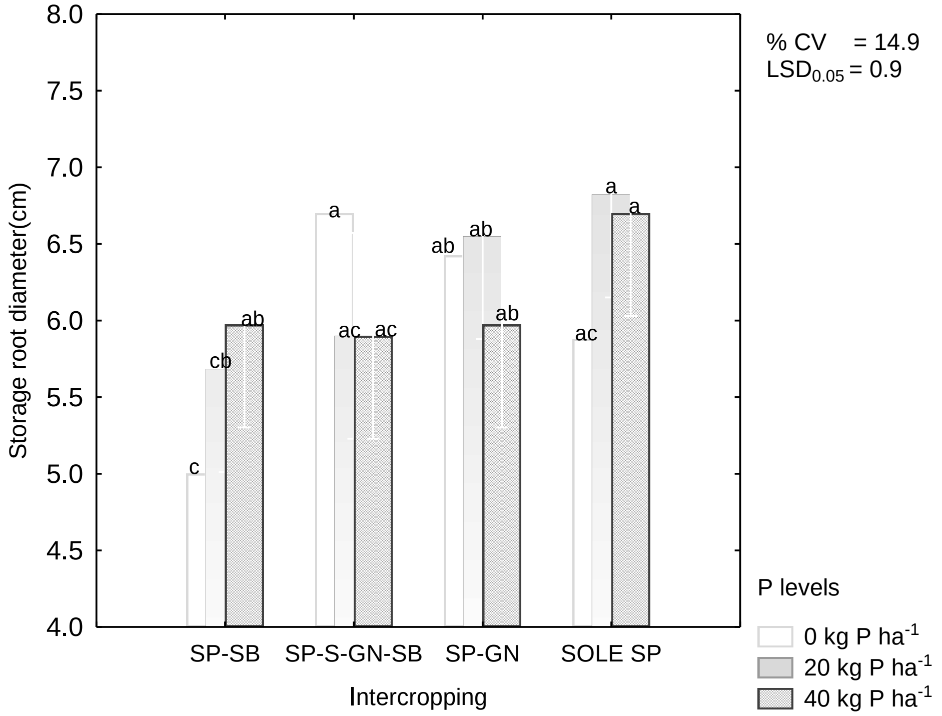
SP-SB-sweetpotato-soybean, SP-GN-SB-sweetpotato-groundnut-soybean, SP-GN-sweetpotato-groundnut, SOLE SP-sole sweetpotato

Lines indicated with the same letter do not differ significantly at P=0.05.

Figure 5.1. Effect of sweetpotato, groundnut and soybean intercropping at three P levels on vine yield at Umbeluzi research station in 2013/14, 2014/15 and 2015/16 growing seasons.

5.3.1.7 Storage root diameter

Sole sweetpotato and sweetpotato- soybean intercropping had no significant difference in storage root diameter at 0 kg P ha^{-1} but at 20 kg P ha^{-1} sweetpotato- soybean intercropping had a significantly lower storage root diameter than sole sweetpotato (P=0.049) (Fig 5.2). Sweetpotato- groundnut intercropping had a significantly higher storage root diameter than sweetpotato-soybean at 0 and 20 kg P ha^{-1} but there was no significant difference between the two cropping systems at 40 kg P ha^{-1} (P=0.049) (Fig 5.2). Intercropping x P interaction was significant for storage root diameter (P=0.049) (Table 5.1).

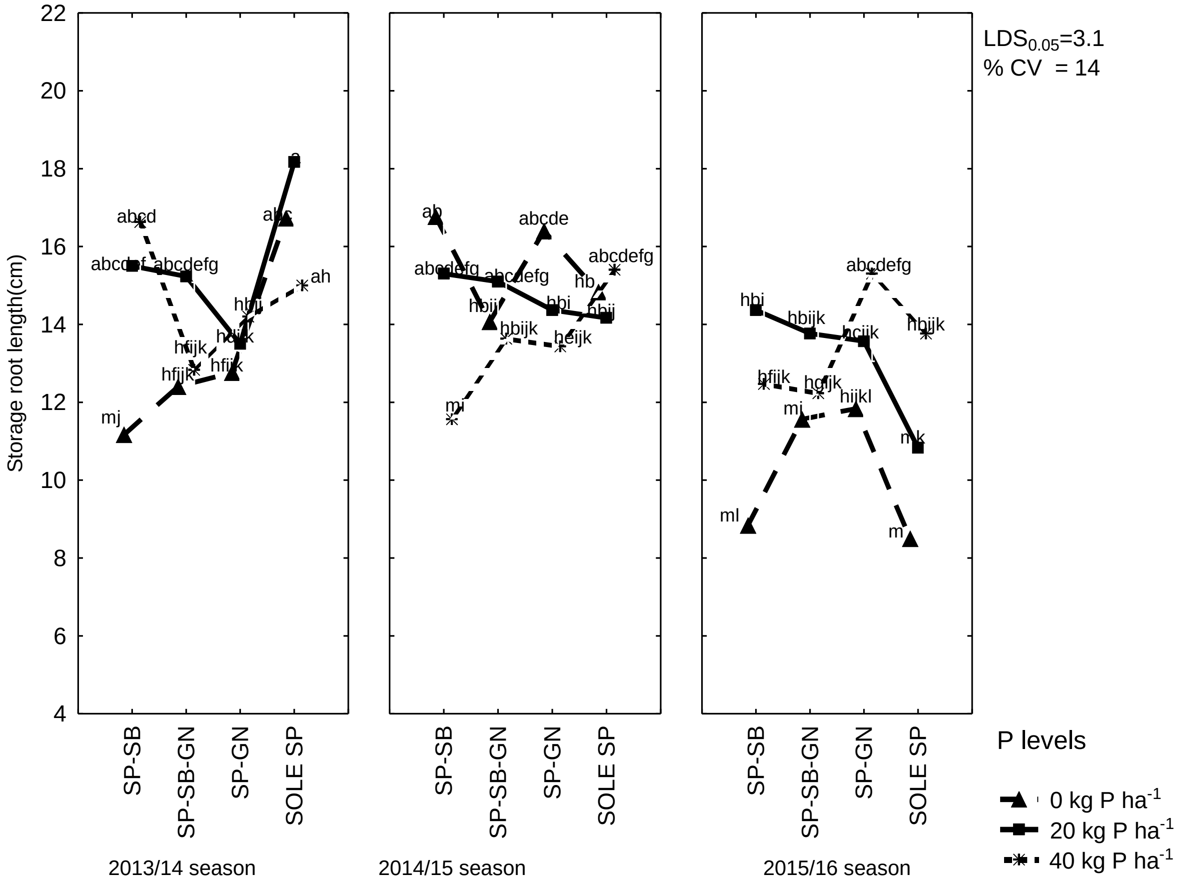


SP-SB-sweetpotato-soybean, SP-SB-GN-sweetpotato-soybean-groundnut, SP-GN-sweetpotato-groundnut, SOLE SP-sole sweetpotato
Bars indicated with at least the same letter do not differ significantly at P=0.05.

Figure 5.2. Effect of intercropping sweetpotato with groundnut and soybean at three P levels on sweetpotato storage root diameter.

5.3.1.8 Storage root length

Intercropping x P x season interaction was significant for storage root length (P=0.027) (Table 5.1). Sweetpotato- soybean intercropping at 20 and 40 kg P ha^{-1} had a significantly higher storage root length than at 0 kg P ha^{-1} in 2013/14 and 2015/16 growing seasons but not in the 2014/15 growing season (P=0.027) (Fig 5.3).

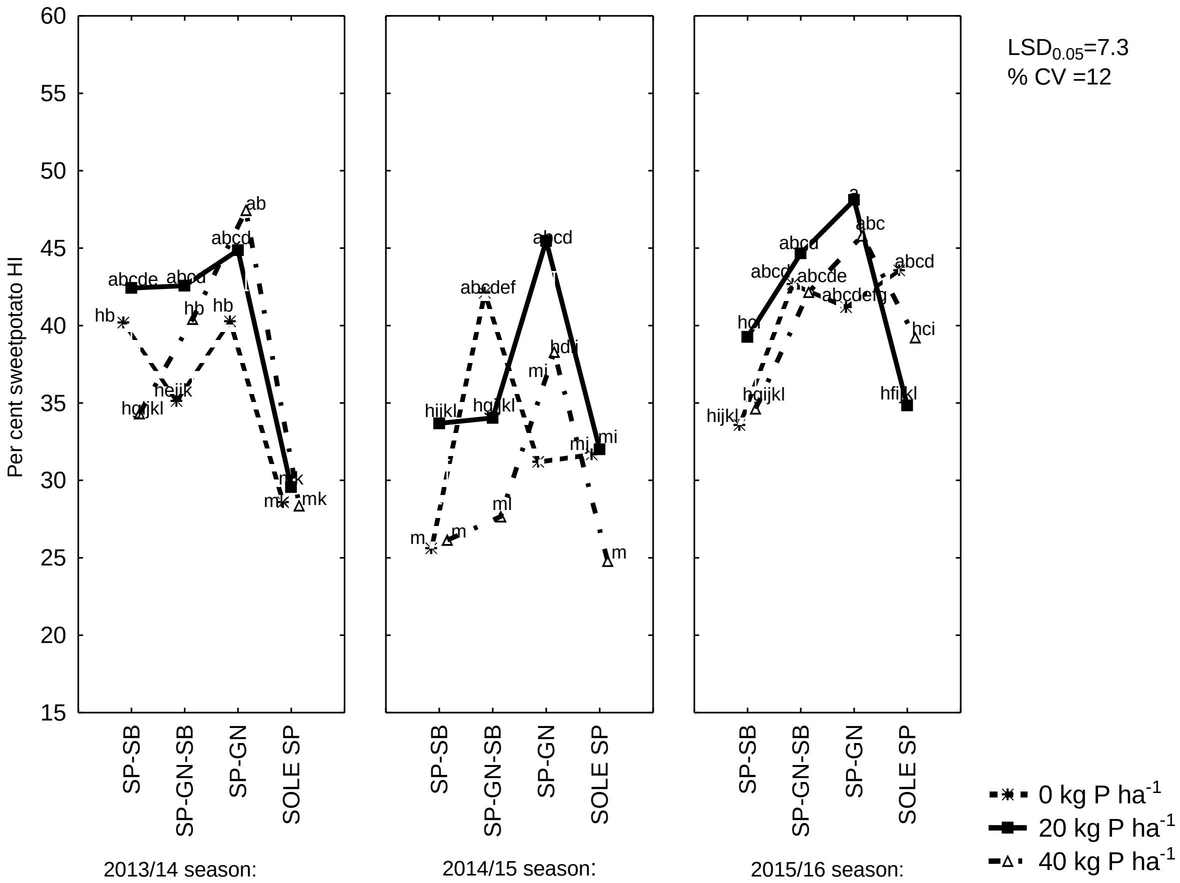


SP-SB-sweetpotato-soybean, SP-SB-GN-sweetpotato-soybean-groundnut, SP-GN-sweetpotato-groundnut, SOLE SP-sole sweetpotato
Lines indicated with the same letter do not differ significantly at P=0.05.

Figure 5.3. Effect of intercropping sweetpotato with groundnut and soybean at three P levels on sweetpotato storage root length at Umbeluzi research station in 2013/14, 2014/15 and 2015/16 growing seasons

5.3.1.9 Percent harvest index

Sweetpotato- groundnut intercropping at 20 kg P ha^{-1} had a significantly higher percent harvest index than sole sweetpotato in all growing seasons but not in all growing seasons at 0 or 40 kg P ha^{-1} (P=0.031) (Fig 5.4). Intercropping x season x P interaction was significant for percent harvest index (P=0.031) (Table 5.1).



SP-SB-sweetpotato-soybean, SP-SB-GN-sweetpotato-soybean-groundnut, SP-GN-sweetpotato-groundnut, SOLE SP-sole sweetpotato

Lines indicated with the same letter do not differ significantly at P=0.05.

Figure 5.4. Effect of intercropping sweetpotato with groundnut and soybean at varying P levels on percent harvest index at Umbeluzi research station during 2013/14, 2014/15 and 2015/16 growing seasons

5.3.1.10 Multiple regression analysis

Regression analysis showed that that there was a positive and significant relationship between total root yield and commercial root yield, and total biomass (Adjusted R^2=0 .99111735) (Table 5.13). However, total storage root yield had a negative relationship with vine yield. In this model, provided that number of roots plant$^{-1,}$ vine yield and total biomass are controlled, a one unit increase in commercial root yield will result in a 0.29 increase in storage root yield (Table 5.13). Provided that number of roots plant^{-1}, commercial root yield and total biomass are held constant, a one unit increase in vine yield would result in a 0.73 units decline in total storage root yield (Table 5.13). In this model 99.1 % of the storage root yield is accounted for by vine yield, total biomass and number of roots plant^{-1} (Table 5.13).

Table 5.13. Multiple regression of commercial root yield, number of roots plant^{-1} vine yield and total biomass on total storage root yield

Regression Summary for Dependent Variable: Yield R= 0.99571553 R²= 0.99144941 Adjusted R²=0 .99111735 F(4,103)=2985.7 p<0.0000						
	b*	Std Error b*	b	Std Error b	T	P value
Commercial root yield	0.2622	0.050567	0.2887	0.05567	5.186	0.000001
Number of roots plant^{-1}	-0.00924	0.009582	-0.0320	0.03319	-0.964	0.337178
Vine yield	-0.71468	0.049267	-0.7344	0.05062	-14.506	0.000000
Total biomass	1.21837	0.083227	0.7442	0.05084	14.639	0.000000

5.3.2 Groundnut yield components

5.3.2.1 Significance of F values

Summary of analysis of variance and significant effects (F values) of intercropping, P and seasons as well as their interactions on pod yield (t ha^{-1}), shelled groundnut yield (t ha^{-1}) and number of pods plant^{-1} of groundnut grown at Umbeluzi research station in Mozambique during 2013/14, 2014/15 and 2015/16 growing seasons are shown in Table 5.14

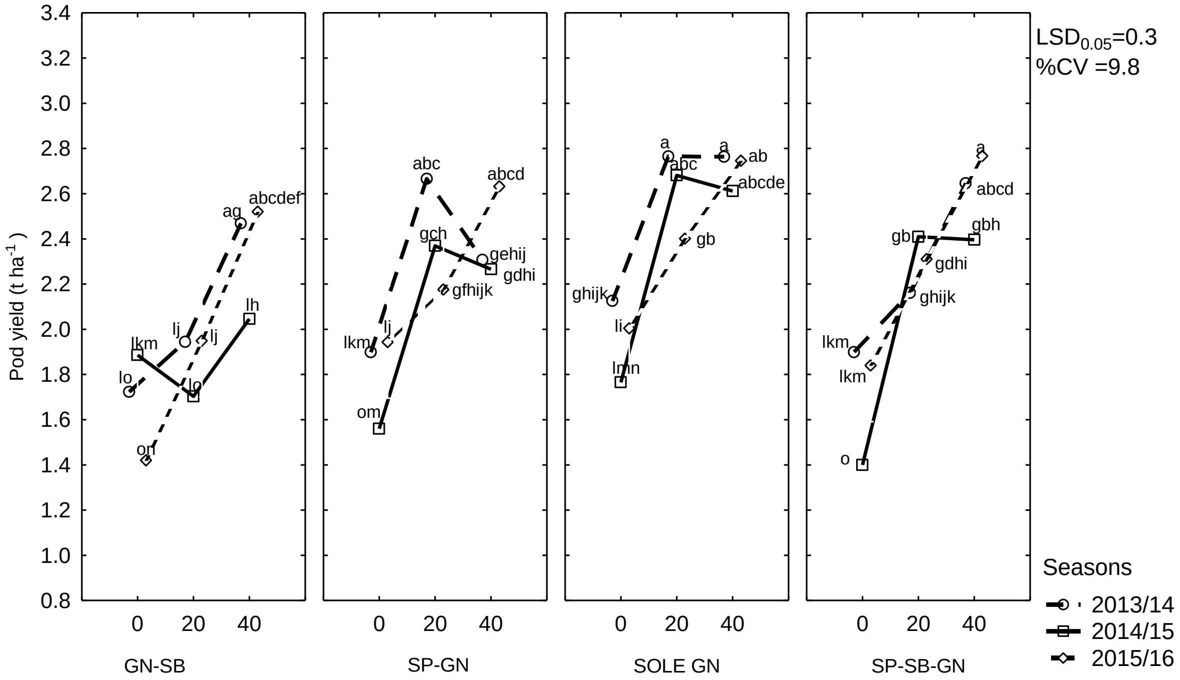
Table 5.14. Summary of significant effects (F- values) from the analysis of variance done on groundnut yield parameters measured at Umbeluzi research station in Mozambique in 2013/14, 2014/15 and 2015/16 growing seasons

Source	**Pod yield (t ha^{-1})**	**Shelled groundnut yield (t ha^{-1})**	**Number of pods plant^{-1}**
	p	**p**	**p**
I	***	***	***
P	***	***	***
S	***	***	***
I x P	***	*	ns
I x S	ns	ns	ns
P x S	*	ns	***
I x P x S	***	ns	***

*, *** Significant at P≤0.05, P≤0.001 respectively, ns denotes non significance at P≤0.05.
I-intercropping, P-phosphorus S- season, I x P-intercropping x Phosphorus, I x S-intercropping x season, I xP x S-intercropping x Phosphorus x season interaction.

5.3.2.2 Pod yield

Groundnut pod yield was significantly higher in sole groundnut than in groundnut-soybean intercropping at 20 kg P ha^{-1} in all growing seasons (P= 0.005) (Fig 5.5). There was no significant difference in pod yield between sole groundnut and groundnut- sweetpotato intercropping at 20 kg P ha^{-1} in all the growing seasons (P>0.05)(Fig 5.5). Sweetpotato-groundnut, Sweetpotato- groundnut- soybean intercropping and sole groundnut had a significantly higher pod yield at 20 kg P ha^{-1} than at 0 kg P ha^{-1} in all growing seasons (P= 0.005) (Fig 5.5). Intercropping x P x season interaction was significant for groundnut pod yield (P= 0.005) (Table 5.6).

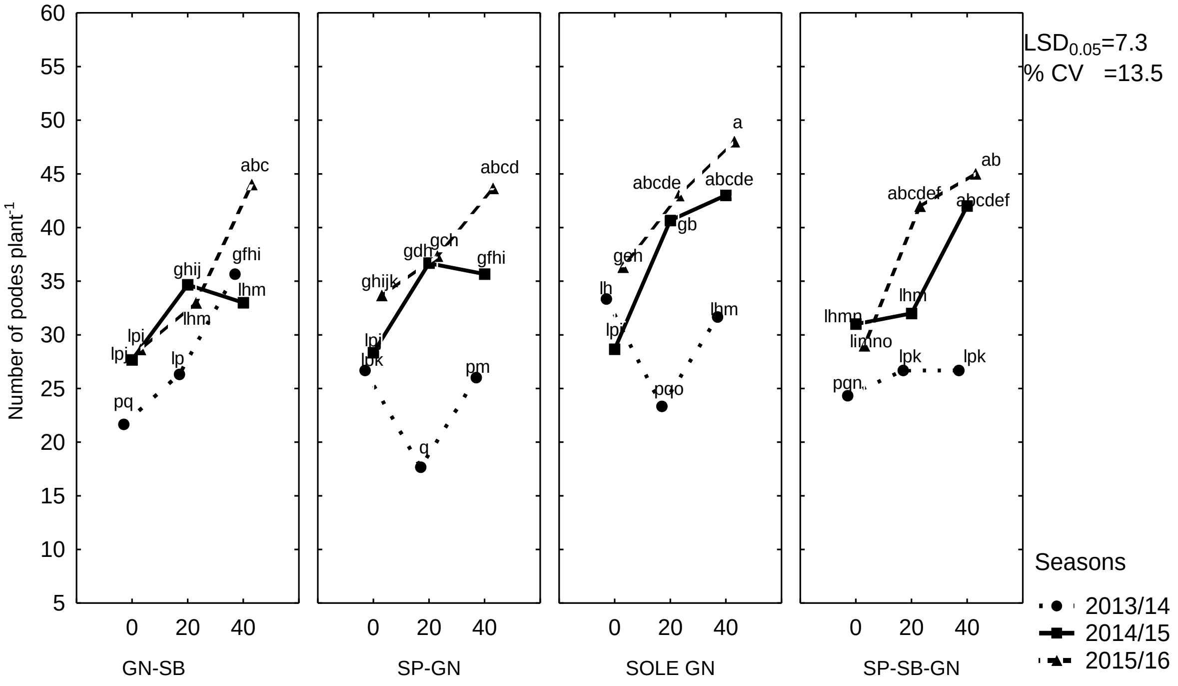


GN-SB-Groundnut-soybean, SP-GN-sweetpotato-groundnut, SOLE GN-sole groundnut, SP-SB-GN-sweetpotato-soybean-groundnut.
Lines indicated with the same letter do not differ significantly at P=0.05.

Figure 5.5. Effect of intercropping sweetpotato with groundnut and soybean and soybean at three P levels on groundnut pod yield (t ha^{-1}) in the 2013/14, 2014/15 and 2015/16 growing seasons at Umbeluzi research station

5.3.2.3 Number of pods plant^{-1}

Intercropping x season x P interaction was significant for groundnut number of pods plant^{-1} (P= 0.005) (Table 5.6). Sole groundnut and sweetpotato- groundnut- soybean intercropping at 20 kg P ha^{-1} had a significantly higher number of pods plant^{-1} than groundnut– soybean intercropping at the same P level in the 2015/16 growing seasons (Fig 5.6).



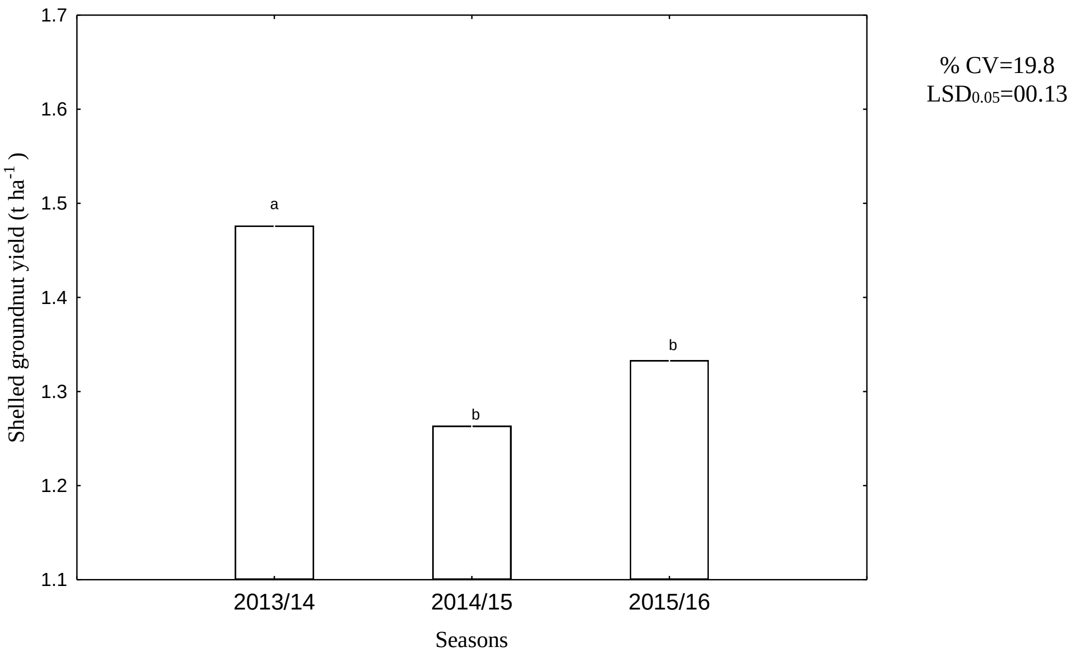
GN-SB-Groundnut-soybean, SP-GN -Sweetpotato-groundnut, SOLE GN-sole groundnut, SP-SB-GN-sweetpotato-soybean-groundnut.

Lines indicated with the same letter do not differ significantly at P=0.05.

Figure 5.6. Effect of intercropping sweetpotato with groundnut and soybean at three P levels on groundnut number of pods plant^{-1} during 2013/14, 2014/15 and 2015/16 growing seasons at Umbeluzi research station

5.3.2.4 Shelled groundnut yield

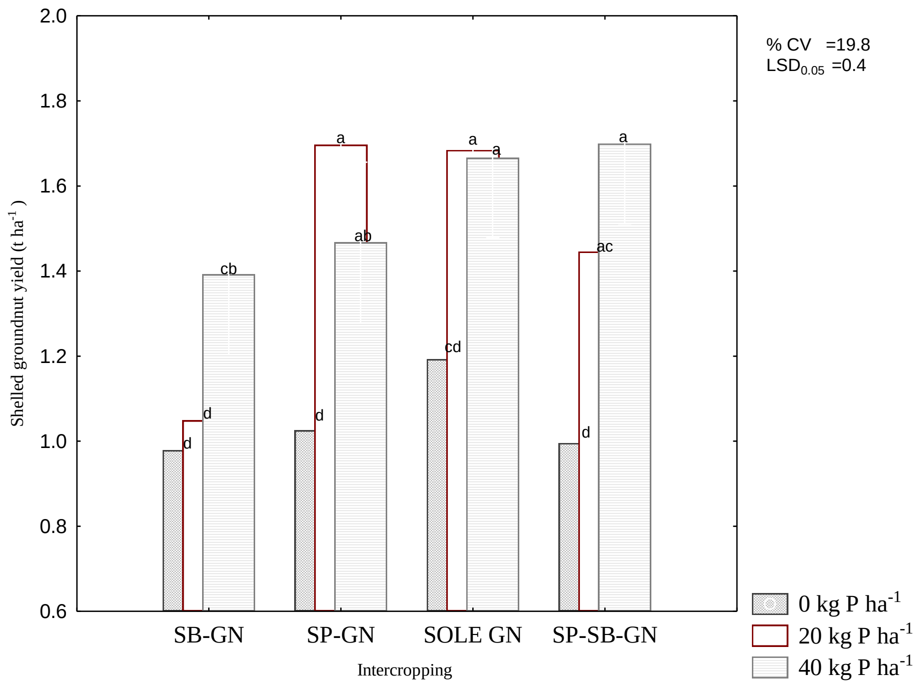
The main effects of season was significant for shelled groundnut yield (P=0.008). There was a significantly higher shelled groundnut yield in the 2013/14 than the other two seasons (Fig 5.7).



Bars indicated with the same letter do not differ significantly at P=0.05.

Figure 5.7. Effect of seasons on the shelled groundnut yield at Umbeluzi research station during 2013/14, 2014/15 and 2015/16 growing seasons.

Intercropping x P interaction was significant for shelled groundnut yield (P=0.017) (Table 5.6). Groundnut- soybean intercropping had a significantly lower shelled groundnut yield than sweetpotato- groundnut at 20 kg P ha^{-1} but the two cropping system had no significant difference at 0 and 40 kg P ha^{-1} (P=0.017) (Fig 5.8). Soybean- groundnut and sole groundnut had no significant difference in shelled groundnut yield at 0 kg P ha^{-1} but sole groundnut had a significantly higher shelled groundnut yield than soybean- groundnut intercropping at 20 and 40 kg P ha^{-1} (P=0.017) (Fig 5.8).



GN-SB-groundnut-soybean, SP-GN-sweetpotato-groundnut, SOLE-GN -Sole groundnut, SP-SB-GN-Sweetpotato-soybean-groundnut.
Bars indicated with the same letter do not differ significantly at P=0.05.

Figure 5.8. Effect of intercropping groundnut with sweetpotato and soybean at three P levels on shelled groundnut yield at Umbeluzi research station during 2013/14, 2014/15 and 2015/16 growing seasons

5.3.3 Soybean yield components

Summary of analysis of variance and significant effects (F values) of intercropping, P and seasons as well as their interactions on pod yield (t ha^{-1}), 100-seed weight and number of pods plant^{-1} of soybean grown at Umbeluzi research station in Mozambique in the 2013/14, 2014/15 and 2015/16 growing seasons are shown in Table 5.15. Table 5.15 show that intercropping x P interaction affected soybean pod yield and number of pods plant^{-1} but did not affect 100-seed weight in soybean crop.

Table 5.15. Summary of significant effects (F- values) from the analysis of variance done on soybean yield parameters measured at Umbeluzi research station in Mozambique in 2013/14, 2014/15 and 2015/16 growing seasons

Source	Pod yield (t ha^{-1})	100- seed weight	Number of pods plant^{-1}
I	*	ns	***
P	***	***	***
S	***	***	***
I x P	***	ns	***
I x S	ns	ns	ns
P x S	ns	ns	ns
I x P x S	ns	**	ns

*, *** Significant at P≤0.05, P≤0.001 respectively, ns denotes non significance at P≤0.05.
I-intercropping, P-phosphorus S- season, I x P-intercropping x Phosphorus, I x S-intercropping x season, I xP x S-intercropping x Phosphorus x season interaction.

5.3.3.1 Soybean pod yield

Sole soybean had a significantly higher pod yield at 0 kg P ha^{-1} than soybean- groundnut and sweetpotato- soybean intercropping but at 40 kg P ha^{-1} the two intercropping systems had a significantly higher pod yield than sole soybean (P=0007) (Table 5.16). There was a 62.5 %, 51.7 % and 38.7 % increase in soybean pod yield by increasing P from 0 to 40 kg ha^{-1} in soybean-groundnut, sweetpotato-soybean and sweetpotato- groundnut- soybean intercropping respectively (Table 5.16). The highest soybean pod yield increase of 51.7 % was observed by intercropping sweetpotato with soybean at 40 kg P ha^{-1} compared to sole soybean (Table 5.16). Intercropping x P interaction was significant for pod yield (P=0.007) (Table 5.15).

Table 5.16. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on soybean pod yield and number of pods plant^{-1} at Umbeluzi research station

Intercropping x P	Pod yield (t ha^{-1})				Number of pods plant^{-1}			
	P levels				P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**	**P0**	**P20**	**P40**	**Mean**
Sole soybean	3.8^{abcd}	3.3^{cde}	2.9^{ef}	**3.3**	119^{d}	125^{cd}	125^{cd}	**123**
Soybean- groundnut	2.4^{f}	3.1^{def}	3.9^{abc}	**3.1**	105^{e}	121^{d}	136^{ab}	**120.7**
Sweetpotato- soybean	2.9^{ef}	4.0^{abc}	4.4^{a}	**3.8**	123^{d}	130^{bc}	137^{a}	**130**
Sweetpotato- groundnut- soybean	3.1^{def}	3.6^{bcde}	4.3^{ab}	**3.7**	120^{d}	125^{cd}	138^{a}	**127**
Mean	**3.1**	**3.5**	**3.9**		**117**	**125**	**134**	**125.3**
% CV	**21.8**				**5.4**			
Intercropping x P LSD$_{0.05}$	**0.7**				**6.3**			

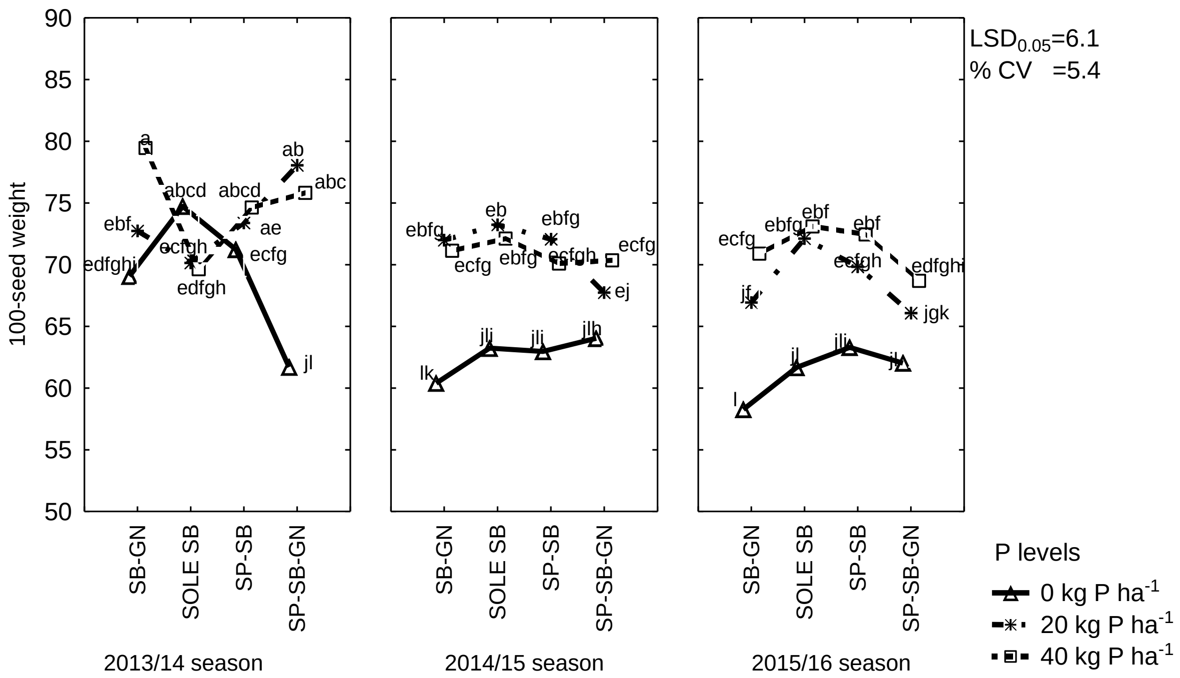
For each parameter, means with at least a common letter are not significantly different, LSD$_{0.05}$

5.3.3.2 Number of soybean pods plant^{-1}

Sole soybean had a significantly higher number of pods plant^{-1} at 0 kg P ha^{-1} but had a significantly lower number of pods plant at 40 kg P ha^{-1} than soybean- groundnut intercropping (P=0001) (Table 5.16). Sweetpotato- soybean at 0 kg P ha^{-1} had a significantly lower number of pods plant^{-1} (31 % lower) than sole soybean but at 40 kg P ha^{-1} there was no difference between the two cropping systems (P=0001) (Table 5.16). There was a significantly higher number of soybean pods plant^{-1} at 20 kg P ha^{-1} than at 0 kg P ha^{-1} in sweetpotato- soybean intercropping treatment (P=0001) (Table 5.16). Intercropping x P interaction was significant for number of pods plant^{-1} (P=0001) (Table 5.15).

5.3.3.3 Soybean 100-seed weight

Intercropping x P x season interaction was significant for soybean 100- seed weight (P=0.003) (Table 5.7). Sweetpotato- groundnut-soybean intercropping had a significantly lower soybean 100-seed weight than sole soybean at 0 kg P ha^{-1} but at 20 and 40 kg P ha^{-1} sweetpotato-soybean- groundnut intercropping had a significantly higher 100-seed weight in 2013/14 growing season (P=0.003) (Fig 5.9). Sole soybean had a significantly higher 100-seed weight at 20 kg P ha^{-1} than at 0 kg P ha^{-1} in the 2014/15 and 2015/16 growing season (P=0.003) (Fig 5.9).



SB-GN-soybean-groundnut, SOLE SB-sole soybean, SP-SB-sweetpotato-soybean, SP-SB-GN-sweetpotato-soybean- groundnut

Lines indicated with the same letter do not differ significantly at P=0.05.

Figure 5.9. Effect of intercropping soybean with sweetpotato and groundnut at three P levels on soybean 100-seed weight at Umbeluzi research station during 2013/14, 2014/15 and 2015/16 growing seasons

5.3.4 Productivity of intercropping system

5.3.4.1 Significance of F values

Summary of significant effects (F values) from analysis of variance done on partial LER for sweetpotato, groundnut and soybean for sweetpotato- soybean, sweetpotato-groundnut and sweetpotato- groundnut- soybean intercropping grown at Umbeluzi research station in Mozambique in 2013/14, 2014/15 and 2015/16 growing seasons are shown in Table 5.17. Both sweetpotato LER and soybean LER ratios were significantly affected by intercropping x P interaction. However, groundnut partial LER was significantly affected by intercropping x P x season interaction Table 5.17.

Table 5.17. Summary of significant effects (F- values) from the analysis of variance done on sweetpotato, groundnut and soybean partial LER at Umbeluzi research station in Mozambique in 2013/14, 2014/15 and 2015/16 growing seasons

Source of variation	**Sweetpotato LER**	**Groundnut LER**	**Soybean LER**
I	***	***	*
P	***	ns	***
S	***	ns	***
I x P	***	ns	***
I x S	***	ns	ns
P x S	ns	ns	*
I x P x S	ns	*	ns
Error			
Total			

*, *** Significant at P≤0.05, P≤0.001 respectively, ns denotes non significance at P≤0.05.
I-intercropping, P-phosphorus S- season, I x P-intercropping x Phosphorus, I x S-intercropping x season, I xP x S-intercropping x Phosphorus x season interaction.

5.3.4.2 Sweetpotato partial LER

Sweetpotato- soybean had a significantly lower sweetpotato partial LER than sweetpotato-groundnut-soybean at 0 and 20 kg P ha^{-1} but the two cropping systems had no significant difference at 40 kg P ha^{-1}. Sweetpotato- groundnut and sweetpotato- groundnut- soybean intercropping had a significantly higher sweetpotato partial LER than sole sweetpotato at all P levels (P= 0.007) (Table 5.18).

Table 5.18. Effects of intercropping sweetpotato, groundnut, soybean at three P levels on sweetpotato LER

Intercropping x P	**Sweetpotato partial LER**			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole soybean				
Sole sweetpotato	1^{e}	1^{e}	1^{e}	**1**
Soybean- groundnut				
Sweetpotato- groundnut	1.6^{a}	1.6^{a}	1.5^{ab}	**1.5**
Sweetpotato- soybean	1.1^{de}	1.2^{cde}	1.2^{cde}	**1.2**
Sweetpotato-groundnut- soybean	1.4^{abc}	1.5^{ab}	1.3^{bcd}	**1.3**
Mean	**1.3**	**1.3**	**1.3**	**1.3**
% CV	**15.6**			
Intercropping x P $LSD_{0.05}$	**0.2**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

Sweetpotato- groundnut intercropping at 0 and 20 kg P ha^{-1} had a partial LER of 1.6. Sweetpotato- groundnut intercropping had a 33.3 % and 25 % more LER than sweetpotato-soybean intercropping at 20 kg P ha^{-1} and 40 kg P ha^{-1} respectively. No significant difference in sweetpotato partial LER between sole sweetpotato and sweetpotato- soybean intercropping occurred at all P levels (P>0.05) (Table 5.18). Intercropping x P interaction was significant for sweetpotato partial LER (P= 0.007) (Table 5.15).

There was no significant difference in sweetpotato partial LER between sweetpotato- groundnut and sweetpotato- groundnut- soybean in 2013/14 and 2014/15 but in 2015/16 sweetpotato- groundnut intercropping had a significantly higher sweetpotato partial LER than sweetpotato- groundnut- soybean intercropping (P=0.007) (Table 5.19). Intercropping x season interaction was significant for sweetpotato partial LER (P=0.007) (Table 5.15).

Sweetpotato- groundnut intercropping had significantly higher sweetpotato partial LER in 2015/16 growing season than all other treatments (P=0.007) (Table 5.19). Sweetpotato- groundnut intercropping had significantly higher sweetpotato partial LER than sweetpotato- soybean intercropping in all growing seasons (P=0.007) (Table 5.19). All intercropping treatments had significantly higher sweetpotato partial LER than sole sweetpotato in 2013/14 (Table 5.19).

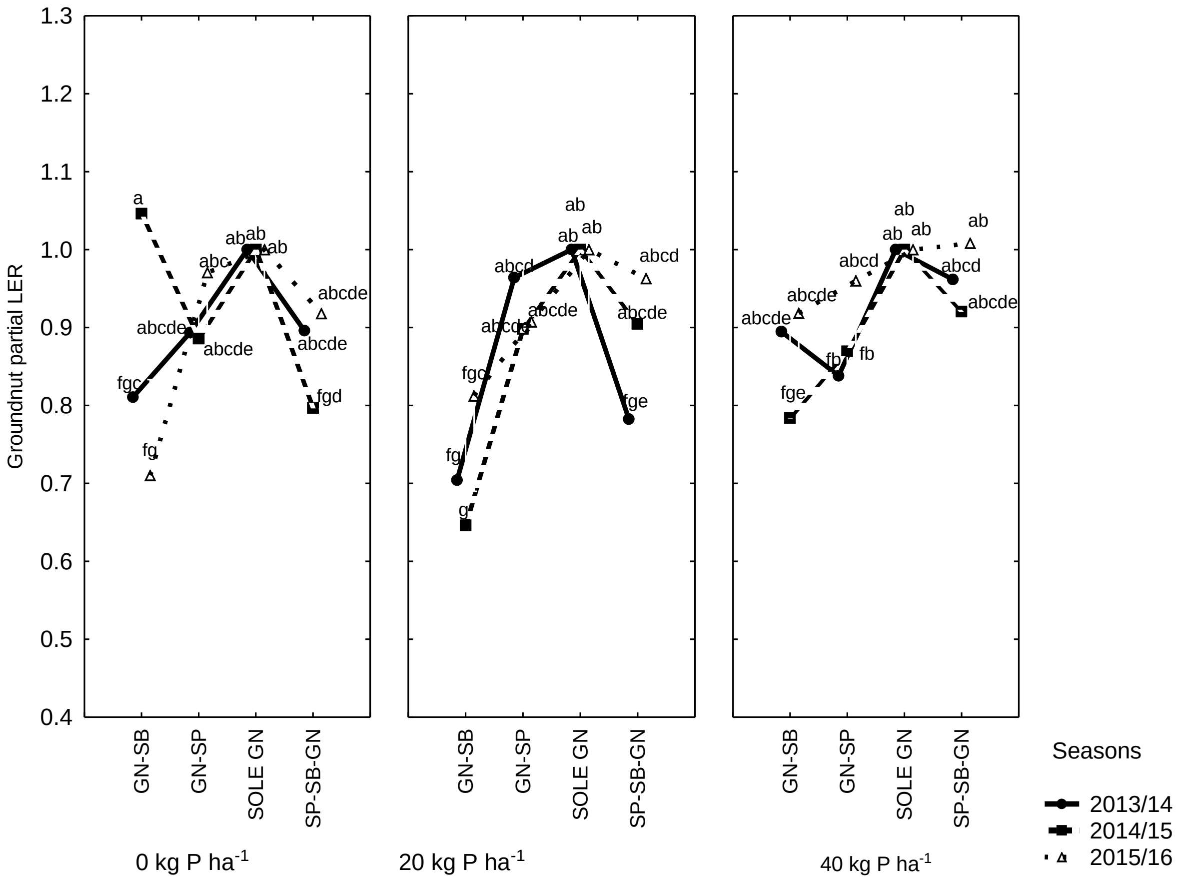
Table 5.19. Effect of intercropping sweetpotato with groundnut and soybean over three growing season on sweetpotato partial LER at Umbeluzi research station

Intercropping x season	**Sweetpotato partial LER**			
	Growing seasons			
Intercropping	**2013/14**	**2014/15**	**2015/16**	**Mean**
Sole sweetpotato	1^{f}	1^{f}	1^{f}	**1**
Sweetpotato- groundnut	1.8^{a}	1.3^{de}	1.6^{abc}	**1.6**
Sweetpotato- soybean	1.5^{bcd}	1.0^{f}	1.1^{ef}	**1.2**
Sweetpotato-groundnut- soybean	1.7^{ab}	1.4^{cd}	1.3^{de}	**1.5**
Mean	**1.5**	**1.2**	**1.3**	**1.3**
% CV	**15.6**			
Intercropping x season LSD $_{0.05}$	**0.2**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

5.3.4.3 Groundnut partial LER

Sole groundnut partial LER was significantly higher at 20 kg P ha^{-1} than groundnut –soybean intercropping but at 40 kg P ha^{-1} there was no significant difference between the two cropping systems in the 2013/14 growing season (P=0.03) (Fig 5.10). Intercropping x P x season interaction was significant for groundnut partial LER (P=0.03) (Table 5.9).



GN-SB-groundnut-soybean, SP-GN -sweetpotato-groundnut, SOLE GN-sole groundnut, SP-SB-GN-sweetpotato-soybean- groundnut
Lines indicated with the same letter do not differ significantly at P=0.05.

Figure 5.10. Effect of intercropping sweetpotato with groundnut and soybean at varying P levels on groundnut partial LER at Umbeluzi research station during 2013/14, 2014/15 and 2015/16 growing seasons

5.3.4.4 Soybean partial LER

Soybean- groundnut and sweetpotato- soybean intercropping had no significant difference in soybean partial LER at 0 and 20 kg P ha^{-1} but sweetpotato- soybean intercropping had a significantly higher soybean partial LER than soybean- groundnut intercropping at 40 kg P ha^{-1} (P=0.002). (Table 5.20). Soybean- groundnut intercropping, at 0 and 20 kg P ha^{-1} had a significantly lower soybean partial LER (0.7) than sole soybean (P=0.002). (Table 5.20). Soybean- groundnut intercropping at both 0 and 20 kg P ha^{-1} reduced productivity unit area^{-1} by 30 % compared to sole soybean crop. Soybean partial LER was 50 % higher in sweetpotato- soybean than soybean- groundnut intercropping at 40 kg P ha^{-1}. Intercropping x P interaction for soybean partial LER was significant (P=0.002) (Table 5.9).

Table 5.20. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on soybean partial LER at Umbeluzi research station

Intercropping x P	**Soybean partial LER**			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole soybean	1^{abc}	1^{abc}	1^{abc}	1
Sole sweetpotato				
Soybean- groundnut	0.7^{d}	0.7^{d}	0.8^{cd}	**0.7**
Sweetpotato- groundnut				
Sweetpotato- soybean	0.8^{cd}	0.8^{cd}	1.2^{a}	**0.9**
Sweetpotato- groundnut- soybean	0.9^{bcd}	0.9^{bcd}	1.1^{ab}	**1.0**
Mean	**0.9**	**0.9**	**1.0**	**0.9**
% CV	**23.6**			
Intercropping x P $LSD_{0.05}$	**0.2**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

There was no significant difference between 0 and 20 kg P ha^{-1} in the 2013/14 and 2015/16 growing seasons but the 20 kg P ha^{-1} treatment had significantly higher soybean partial LER than at 0 kg P ha^{-1} in the 2014/15 growing season (P=0.24)(Table 5.21). Soybean partial LER was significantly higher at 40 kg P ha^{-1} than at 20 kg P ha^{-1} in the 2013/14 but in 2014/15 and 2015/16 there was no significant difference in soybean partial LER between 20 and 40 kg P ha-

[1] in the 2014/15 growing season (Table 5.21). P x season interaction was significant for soybean partial LER (P=0.024) (Table 5.15).

Table 5.21. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on soybean partial LER at Umbeluzi research station in the 2013/14, 2014/15 and 2015/16 growing seasons

P x season	**Soybean partial LER**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	0.8^{e}	1.0^{de}	0.8^{e}	0.9
P20	0.9^{de}	1.3^{bc}	1.0^{de}	1.1
P40	1.6^{a}	1.5^{ab}	1.1^{cd}	1.4
Mean	**1.1**	**1.3**	**1.0**	**1.1**
% CV	**23.6**			
P x seasonLSD$_{0.05}$	**0.2**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

5.4 Discussion

Intercropping is an effective approach to diversify farming systems, maximize the use of farmland, and provide numerous agroecosystems services, such as the maintenance of soil fertility, moisture conservation and weed control (Ibeawuchi 2007, Seran and Brintha 2010). Sweetpotato-groundnut and sweetpotato- groundnut- soybean intercropping systems at 0 and 20 kg P ha^{-1} had a significantly higher storage root yield compared to sole sweetpotato at the same P levels possibly due to N fixation by the legumes. Sweetpotato- groundnut intercropping at 20 kg P ha^{-1} also had a higher sweetpotato harvest index than sole sweetpotato probably due to nutrient use efficiency and moisture conservation in the intercropping system that resulted in high total storage root yield. The study by Li et al. (2001) reported that yield increases in intercropping systems is given by the facilitation in nutrient acquisition, specially N and K, possibly due to a variety of root architecture reaching different regions of the soil and due to N fixation in the leguminous crop. Farmers can take advantage of the sweetpotato-groundnut intercropping system at 20 kg P ha^{-1} cited above in their sweetpotato production system.

The highest mean sweetpotato partial land equivalent ratio of 1.6 was obtained in sweetpotato- groundnut intercropping at 20 kg P ha^{-1}, indicating that higher productivity per unit area was achieved by growing these crops together rather than growing them separately. Therefore farmers are recommended to adopt sweetpotato- groundnut intercropping at 20 kg P ha^{-1} as they would make efficient use of their scarce land resource in the context of depleting soil fertility and high food demand in the country. Ossom et al. (2005), who worked on mixtures of grain legumes and sweetpotato, reported LERs that ranged from 1.48 to 1.79, representing a yield advantage of 48-79 % from the intercropping systems.

Significantly lower sweetpotato partial LER on sweetpotato- soybean intercropping compared to sweetpotato- groundnut intercropping at all P levels could be attributed to the shading effect of soybean on sweetpotato that depressed sweetpotato growth and total storage root yield. Mwanga and Zamora (1988) working on the effects of different shade levels on sweetpotato revealed that shading by 31 to 67 % reduced storage root yield by 11-97 %. Given the lower yields resulting from sweetpotato- soybean intercropping, and the observed lower LER compared to sweetpotato- groundnut intercropping system, sweetpotato-soybean intercropping should be discouraged.

A 48.3 % higher commercial root yield in sweetpotato-groundnut intercropping compared to sole sweetpotato at 20 kg P ha^{-1} was observed in this study. This was probably caused by less pest and disease damage, nitrogen fixation and moisture conservation resulting from rapid groundcover by groundnut under this intercropping system. The results are similar to reports by Byamukama et al (2007) that sweetpotato commercial root yield increased significantly due to reduced pest and disease incidence in sweetpotato-maize intercropping. Sweetpotato-groundnut intercropping may be a strategy that farmers in Mozambique could adopt to increase ecological diversity and protecting sweetpotato from insect damage that may result in increased sweetpotato commercial root yield.

Sole sweetpotato at 40 kg P ha^{-1} had an increased vine yield compared to sweetpotato-groundnut and sweetpotato- groundnut- soybean intercropping in the 2013/14 and 2014/15 growing seasons. This could probably be explained based on less available P content in the study soil which might have led to higher response to increased supply of the nutrient as observed by Abdel-Razzak et al. (2013) that supply of P in low P soils stimulate vine growth.

Sweetpotato- groundnut intercropping had a higher number of storage roots plant^{-1} than all other treatments at 20 kg P ha^{-1}. The increase in the number of storage roots plant^{-1} in this study could have been caused by the facilitation effect of groundnuts through a better use of the available resources (water and nutrients), N fixation and moisture conservation due to rapid groundcover. The results are similar to reports by Njoku et al (2007) that melon (planophile) improved the yield of companion crops by conserving soil moisture and reducing high noon temperature, thereby making the environment more conducive for plant growth and development. In addition Sivakumar (1993) also reported that efficient and complete use of growth resources such as solar energy, soil nutrients and water is one of the advantages of intercropping systems over sole crops. Sweetpotato-soybean intercropping had lower number of storage roots plant^{-1} than sole sweetpotato in the 2014/15 growing season probably due to shading effects of soybean on sweetpotato in which less assimilates were translocated to for the formation and bulking of storage roots. Improved productivity can result from either greater interception of solar radiation, higher light use efficiency, or a combination of the two (Willey 1990) and therefore shading impairs productivity and storage root number. Oswald et al. (1995) and Palaniswami and Peter (2008) revealed a reduction in numerical proportion of storage roots due to shading. There is not much benefit in sweetpotato- soybean intercropping in sweetpotato- production systems although the system has some soil fertility benefits that have been reported in Chapter 3 of this thesis.

Sole sweetpotato at 20 kg P ha^{-1} had a significantly higher storage root diameter than sweetpotato-soybean intercropping. This was probably caused by the shading effect that soybean imposed on sweetpotato resulting in reduced assimilates being translocated and stored in the storage roots. Zara et al. (1982) observed a 32-92 % reduction in storage root diameter when sweetpotato was grown under shade of coconut in Philippines. Light is one of the most important factor in plant growth and reproduction and it is different from other growth resources in that it is only instantaneously available and thus must be instantaneously intercepted to be of benefit while other resources are typically pools awaiting plant exploitation (Gebru 2015). Intercropping sweetpotato with legumes of the same height could be useful in ensuring that both component crops have access to full solar radiation that is necessary for biological processes. Sweetpotato- soybean intercropping may not be the appropriate crop combination for increased storage root diameter.

Total biomass was higher among all intercropping treatments than sole sweetpotato at 0 kg P $ha^{-1.}$ and was also higher at 40 kg ha^{-1} than at 20 and 0 kg ha^{-1}in all treatments. These results probably reveal that with intercropping systems there were efficient use of resources such as nutrients and moisture that promoted high biomass yield. Fertilisation by P at 40 kg ha^{-1} may have improved fibrous root formation and root surface area. Long roots and high root surface enable the plant to scavenge for nutrients especially P that is relatively immobile in the soil thereby providing a plant with a competitive edge for soil nutrients and water (Rashid and Waithaka 2009) resulting in high biomass in sweetpotato production systems.

Groundnut pod yield, pods $plant^{-1}$ and shelled pod yield was higher in sole groundnut at 20 kg P ha^{-1} than in groundnut- soybean intercropping. Shading effect of soybean on groundnut could probably be responsible for low yield components as reported by Willey (1990). The results further indicate that P fertilisation is necessary for physiological processes resulting in high groundnut pod yield at 20 kg P ha^{-1}. The results are in general agreement with Hossain et al. (2007) who revealed highest groundnut pod yield at 60 kg P ha^{-1} and lowest pod yields at 0 kg P ha^{-1}. In groundnut production systems farmers are recommended not to intercrop groundnut with soybean but rather intercrop with plants of similar height.

There was a higher soybean pod yield and 100-seed weight at 40 kg P ha^{-1} than at 0 kg P ha^{-1} for all intercropping treatments. The observed increase can be attributed to the role of P in N fixations that subsequently contributed to high pod yield and 100-seed weight. The results are in consonance with Mahamood et al (2009) who reported a positive soybean yield and number of seed plant^{-1} at 30 kg P ha^{-1}. The use of P fertiliser is generally suggested to correct P deficiency. However, P fertiliser is quickly fixed into forms unavailable to plants by Fe and Al oxide in the soil (Sample et al. 1980). Under such circumstances, integration of plant genotypes that can make the most efficient use of the P supplied by the soil represent a key element of sustainable cropping systems among smallholder farmers (Horst et al. 2001).

5.5 Conclusion

The study has shown that sweetpotato- groundnut intercropping resulted in higher storage roots yield and higher number of storage roots plant^{-1} compared with sole sweetpotato. Land equivalent ratio for all intercrops was above 1.0, indicating that higher productivity unit^{-1} area was achieved by growing these crops together than by growing them separately. Sole groundnut at 20 kg P ha^{-1} resulted in higher pod and shelled groundnut yield and number of pod plant^{-1} than in groundnut- soybean indicating that it is better to grow groundnut alone than to intercrop it with soybean. However, groundnut may be intercropped with sweetpotato since no significant difference was noted in pod yield between sole groundnut and sweetpotato-groundnut intercropping.

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Chapter 6 : Effects of intercropping orange-fleshed sweetpotato with groundnut and soybean at three P application levels on the nutritional quality of sweetpotato storage roots.

Abstract

Micronutrient deficiencies that afflicts more than 2 billion individuals globally has not received adequate attention through cheap and more accessible food based approaches in Mozambique. Information on agronomic practices to combat micronutrient deficiency in Mozambique is limited. An experiment was conducted to investigate the influence of intercropping orange-fleshed sweetpotato with groundnut and soybean at different P levels on nutritional quality of sweetpotato storage roots at Umbeluzi research station during the 2013/14, 2014/15 and 2015/16 growing seasons. The experiment was 4 x 3 factorial in a randomized complete block design in a split plot arrangement. The main plot treatments were sweetpotato sole crop, sweetpotato-groundnut, sweetpotato-soybean and sweetpotato- groundnut- soybean intercropping. The subplot treatments were 0, 20 and 40 kg P ha^{-1} applied at planting. After each harvest crop residues were incorporated into the soil. Percent dry matter content, glucose, fructose, sucrose, starch, β-carotene, zinc (Zn) and iron (Fe) content of the sweetpotato storage roots were determined using near-infrared reflectance spectroscopy (NIRS). Percent dry matter content was higher in sole sweetpotato at 40 kg P ha^{-1} compared to any other treatments involving soybean . Highest mean sucrose content of 11.6 % was observed on sole sweetpotato at 20 kg P ha^{-1}. Sweetpotato-groundnut and sole sweetpotato had more glucose content in the 2014/15 and 2015/16 growing seasons at 20 and 40 kg P ha^{-1} compared to the 2013/14 growing seasons. A 10.8 % mean starch content increase was obtained by increasing P application from 0 kg P ha^{-1} to 40 kg P ha^{-1}. There was a significant and positive correlation (R^2 =0.311122008) between starch and percent dry matter in the storage roots. There was an average increase of 24.9 % β-carotene content in the storage roots in the 2015/16 growing season compared to 2013/14 growing season and β-carotene yield was higher in sweetpotato-groundnut

intercropping than sole sweetpotato at 20 kg P ha^{-1}. There was an 18.2 % and 17.5 % higher Fe content in the 2015/16 than 2013/14 and 2014/15 growing seasons respectively and highest Fe yield was observed in the 2015/16 growing season on sweetpotato- groundnut intercropping. Sweetpotato- legume intercropping had higher Zn content in the storage roots in the 2015/16 compared to the 2013/14 growing seasons. Zinc yield was best in sweetpotato-groundnut intercropping at 40 kg P ha^{-1} in the 2015/16 growing season. There was no significant difference in Zn content between 0 and 20 kg P ha^{-1} in all treatments in all growing seasons. The results suggests that P is important for improving dry matter content, glucose, starch and sucrose in sweetpotato storage roots. It is recommended that farmers intercrop sweetpotato and groundnut at 20 P kg ha^{-1} and incorporate crop residues for improved Fe and Zn content in OFSP.

Key words: Deficiency, intercropping, micronutrient, orange fleshed sweetpotato,

6.1 Introduction

'Hidden hunger' due to micronutrient (mineral and vitamin) deficiencies is widespread throughout the world particularly in sub-Saharan Africa (WHO 2009). Micronutrient malnutrition is a concern given the potentially irreversibility of its effects. A short period of severe micronutrient malnutrition during pregnancy or during early childhood can permanently impair a child's future physical ability and cognitive capacities (Hotz and Brown 2004). Vitamin A deficiency (VAD) is a leading cause of acquired blindness in children (WHO 2009). Zinc (Zn) deficiency causes abnormal labour and foetal abnormalities in pregnant women, retards physical growth and cognitive capacity in children, and delays sexual maturity in adolescents (Hotz and Brown 2004). Iron (Fe) deficiency is one of the most common nutritional disorder worldwide and a leading cause of anemia (McDowell 2003).

Food fortification aimed at increasing micronutrient intake has been widely implemented in the developed world. Oils, sugar and cereal flours are commonly fortified with vitamin A, iodized salt is now consumed across much of the globe, white bread and other processed staples/cereals are commonly fortified with Fe and even Zn. Food fortification is effective if implemented amongst a population of well-educated consumers who are aware of the value of added micronutrients in their food and are willing to pay for that additional value (Dary and Mora 2002). Serious micronutrient deficiencies commonly arise in rural areas where families depend heavily on locally grown food crops and have little access to processed foods. In Mozambique, the majority of the population is poor with 70 % of the population living in rural areas and the majority living with less than a dollar per day and therefore are not able to meet the cost of fortified foods.

Biofortification offers a new mechanism for expanding micronutrient supplies from specific farming systems. Biofortification is designed to target resource-poor, rural agrarian populations who cannot afford to purchase most fortified foods (Miller and Welch 2013). So far, biofortified foods have targeted vitamin A, iron, and zinc.

The current emphasis on promoting inorganic fertilizer use in African agriculture can increase or decrease the micronutrient content of crops including biofortified crops (Welch 2001). Excessive application of NPK fertilizer decreases the iron content of high-yielding tropical rice (Panda et al. 2012). Incorporation of crop residues into the soil has been shown to increase Fe and Zn availability in the soil (Srinivasarao and Sudha 2013). Intercropping and rotational systems with legumes have been shown to reduce pH through proton (H^+) extrusion in the rhizosphere, increasing Fe^{3+} 'chelates' solubility and resulting in availability of Fe which can then be up-taken by plants (Robinson et al. 1999). Cropping system and fertiliser application also affect carbohydrate synthesis in sweetpotatoes. Thus, having only biofortified crops is not enough since research has shown that agronomic practices and cropping systems may affect micronutrient availability and carbohydrates synthesis in horticultural crops.

The objective of this study was to evaluate the influence of intercropping orange-fleshed sweetpotato with groundnut and soybean at three P levels on nutritional quality of sweetpotato storage roots.

6. 2 Materials and methods

6. 2. 1. Site

The experiment was carried out over three growing seasons at Umbeluzi research station whose site description is given in 3.2.3 in Chapter 3 of this thesis. Temperature and rainfall distribution during the growing seasons is shown in Table 3.1.

6. 2. 2 Experimental design

The experiment was laid out in a 4 x 3 factorial set up in a split plot in a randomized complete block design with three replications. Sweetpotato variety, Namanga was intercropped with groundnut variety Bebiano Vermelho and soybean variety Zamboane. The main-plot treatment were 5 crop combinations (i) sole sweetpotato crop, (ii) intercropping two rows of groundnut between sweetpotato rows, (ii) intercropping one row of soybean between sweetpotato rows (iv) intercropping two rows of groundnut between sweetpotato row followed by a row of soybean between sweetpotato rows. The sub-plot treatments comprised of three levels of P (0, 20 and 40 kg ha^{-1}) applied at the beginning of each planting. The rest of the procedure is the same as shown in section 3.2.3 in Chapter 3 of this thesis

6.2.3 Sweetpotato nutritional quality traits measured

At harvest, a sample of 5 sweetpotato storage roots with no physical damage, weighing 100 to 300 g, were taken for β- carotene, Zn, Fe, dry matter, starch, glucose, fructose and sucrose determination. The roots were washed and rinsed with abundant tap water, peeled, and rinsed again using distilled de-ionised water. Each root was cut longitudinally into four quarter sections, and two opposite sections sliced using stainless steel blades, to obtain a 100 g compound sample that was placed in transparent polythene bags, and freeze dried at -31^{o}C for 72 hours. Dry samples were weighed, milled into flour in a stainless steel mill, and stored in paper bags. Percent root dry matter was determined as a ratio of dry to fresh weights. β-Carotene, Zn, Fe, starch, glucose, fructose and sucrose in the milled samples of freeze dried roots was measured with the near-infrared reflectance spectroscopy (NIRS) technology (Shenk and Westerhaus 1993). Each milled sample material (two times 3 g), was analysed by NIRS within the range of 400 to 2500 nm, on a NIRS monochromator model 6500 (NIR Systems, Inc. Silver Spring, MD); using small ring cups with sample autochanger. Near-infra-red spectra of each sample were used to determine β-carotene with the latest calibration version for sweetpotato freeze dried samples. In this version, the correlations in cross-validation between standard laboratory reference methods and NIRS are 0.97 for β-carotene (Zum et al. 2009). The reference method for NIRS calibration was high performance liquid chromatography (HPLC) for β-carotene, Zn, Fe, starch, glucose, fructose and sucrose, according to Rodriguez-Amaya and Kimura (2004). All nutritional analyses were performed at International Potato Centre Nutritional Quality Laboratory in Maputo, Mozambique. Micronutrient yield, in kg ha^{-1} on a dry matter basis, was determined by multiplying sweetpotato total storage root yield on a dry matter basis by micronutrient content in kg kg^{-1} of OFSP.

6.2.4 Data analysis

All data collected was analysed using Statistica (13.0) software following standard analysis of variance procedures (Gomez and Gomez 1984). Means were separated using Fishers LSD at 5 % probability. Correlations among percent dry matter content, β- carotene content (mg $100g^{-1}$ DW), Fe (mg $100g^{-1}$ DW), Zn (mg $100g^{-1}$ DW), percent glucose and percent starch were determined using correlation matrices in Statistica (13.0) software. Multiple regression analysis of storage root yield, β- Carotene, Fe and Zn content in sweetpotato storage roots were determined using Statistica (13.0) software.

6. 3 Results

6.3.1 Significance of F values

A summary of significant effects (F values) from analysis of variance done on percent starch, dry matter content, fructose, glucose and sucrose in the sweetpotato storage roots grown at Umbeluzi research station over three growing seasons is shown in Table 6.1. All the measured parameters were significantly affected by intercropping x P x season interaction except percent starch content (Table 6.1). Percent starch content was affected by P x season interaction and all the main effects.

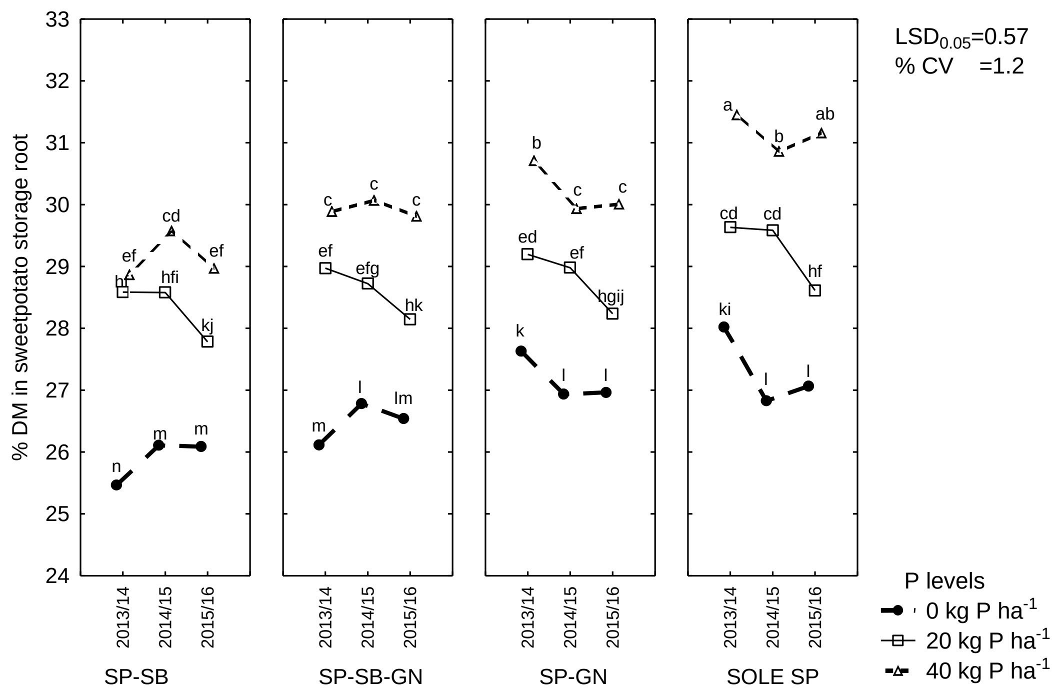
Table 6.1: Summary of significant effects (F- values) from the analysis of variance done on percent starch, percent dry matter, percent fructose, percent glucose and percent sucrose measured in Mozambique in 2013/14, 2014/15 and 2015/16 growing seasons

Source	% Starch	% Dry matter	% Fructose	% Glucose	% Sucrose
I	***	***	***	*	***
P	***	***	***	ns	***
S	***	***	***	***	***
I x P	ns	***	***	ns	ns
I x S	ns	***	***	***	*
P x S	***	***	***	***	ns
I x P x S	ns	*	*	*	*
Error					
Total					

*, *** Significant at P≤0.05, P≤0.001 respectively, ns denotes non significance at P≤0.05.
I- intercropping, P- phosphorus levels, S - season, I x P- intercropping x P, I x S-Intercropping x season, P x S-P x season, I x P x S- intercropping x P x season interactions.

6.3.2 Percent dry matter content in the storage root

Sweetpotato- soybean and sweetpotato- groundnut at 20 kg P ha^{-1} had no significant difference in percent dry matter in all three seasons but at 40 kg P ha^{-1}, sweetpotato- groundnut intercropping had a significantly higher percent dry matter content in the 2013/14 and 2015/16 growing seasons (P=0.04) (Fig 6.1). Sweetpotato- groundnut- soybean and sweetpotato- soybean intercropping at 0 kg P ha^{-1} had no significant difference in percent dry matter content in 2015/16 but at 40 kg P ha^{-1}, sweetpotato - groundnut- soybean had significantly higher percent dry matter content than sweetpotato-soybean in the 2015/16 growing season (P=0.04) (Fig 6.1). Percent dry matter content was significantly lower at 0 kg P ha^{-1} than at both 20 and 40 kg P ha^{-1} in all treatments in all growing seasons (P=0.04) (Fig 6.1). Intercropping x P x season interaction was significant for percent dry matter in the sweetpotato storage roots (P=0.04).

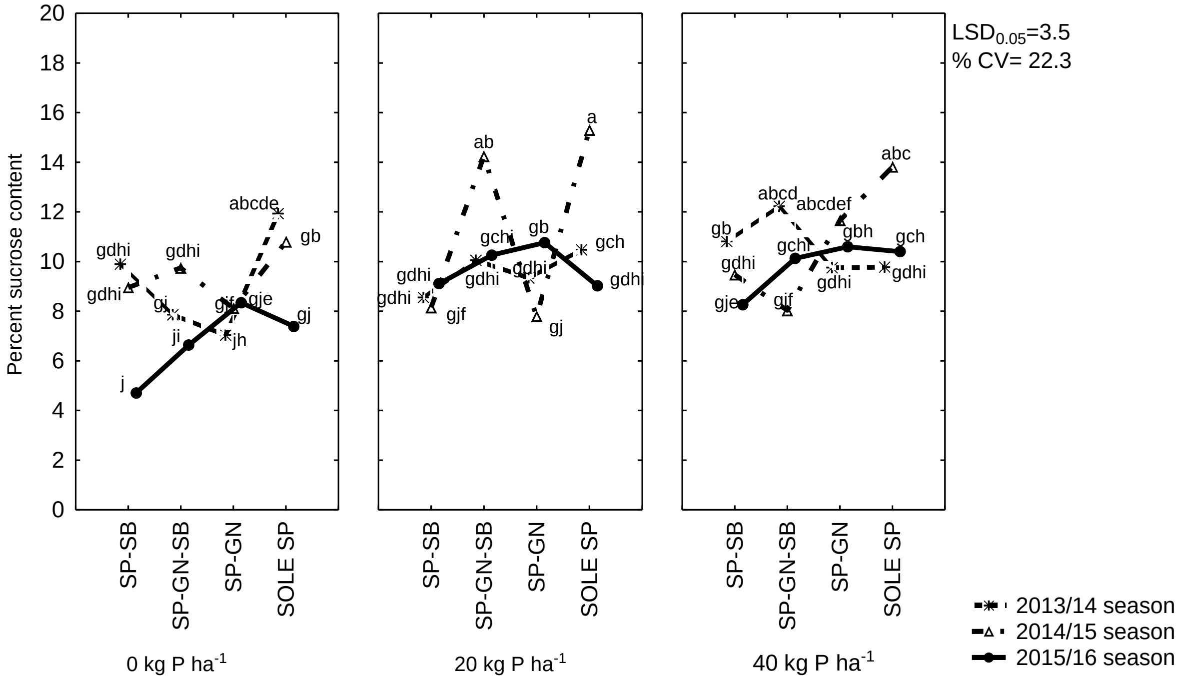


SP-SB-sweetpotato-soybean, SP-SB-GN-sweetpotato-soybean-groundnut, SP-GN-Groundnut-soybean, SOLE SP-sole sweetpotato.
Lines indicated with the same letter do not differ significantly at P=0.05.

Figure 6.1. Effect of intercropping sweetpotato and groundnut at different P levels on percent dry matter content in sweetpotato storage roots grown at Umbeluzi research station in 2013/14, 2014/15 and 2015/16 growing seasons.

6.3.3 Percent sucrose content

Sole sweetpotato and sweetpotato-soybean intercropping at 0 kg P ha^{-1} had no significant difference in percent sucrose content in the 2014/15 growing season but sole sweetpotato had significantly higher percent sucrose content than sweetpotato- soybean at 20 and 40 kg P ha^{-1} in the 2014/15 growing season (P=0.04) (Fig 6.2). There was no significant difference in percent sucrose between sweetpotato- groundnut- soybean intercropping, and sweetpotato-groundnut and sole sweetpotato at 0 kg P ha^{-1} in 2013/14 but at 40 kg P ha^{-1}, sweetpotato-groundnut-soybean intercropping had significantly higher percent sucrose content than sweetpotato- groundnut and sole sweetpotato cropping systems (P=0.04) (Fig 6.2). Sole sweetpotato had a significantly higher percent sucrose content than sweetpotato- soybean at 20 and 40 kg P ha^{-1} in 2014/15 growing season (P=0.04) (Fig 6.2). There was no significant difference in percent sucrose content between 20 and 40 kg P ha^{-1} in all treatments in all the growing seasons except in sweetpotato- groundnut- soybean intercropping (P>0.05) (Fig 6.2). Intercropping x P x season interaction was significant for percent sucrose content in sweetpotato storage roots (P=0.04) (Table 6.1).

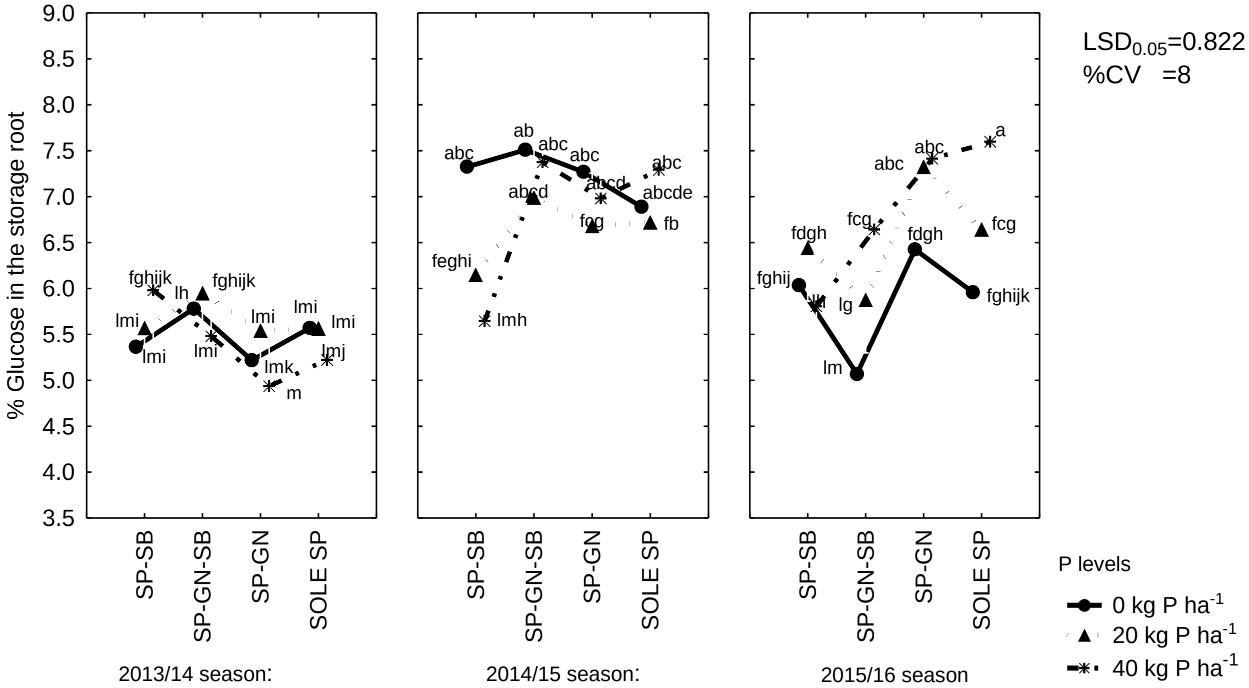


SP-SB-sweetpotato-soybean, SP-GN- SB -sweetpotato-soybean-groundnut-SP-GN-sweetpotato-groundnut, SOLE SP-sole sweetpotato,
Lines indicated with the same letter do not differ significantly at P=0.05.

Figure 6.2: Effect of intercropping sweetpotato and groundnut at different P levels on percent sucrose content in sweetpotato storage roots grown at Umbeluzi research station in the 2013/14, 2014/15 and 2015/16 growing seasons

6.3.4 Percent glucose content

Sweetpotato- soybean at 40 kg P ha^{-1} had no significant difference with sole sweetpotato in the 2013/14 growing season but in the 2014/15 and 2015/16 growing seasons sole sweetpotato had a significantly higher glucose content than sweetpotato- soybean intercropping system (P<0.05) (Fig 6.3). Sweetpotato- groundnut intercropping and sole sweetpotato at 20 and 40 kg P ha^{-1} had significantly higher glucose in 2014/15 and 2015/16 compared to the same combination in the 2013/14 growing season (P<0.05) (Fig 6.3). There was no significant difference in glucose content between sweetpotato- groundnut intercropping and sole sweetpotato at 40 kg P ha^{-1} in all the growing seasons (P>0.05) (Fig 6.3). Sole sweetpotato at 40 kg P ha^{-1} had a significantly higher glucose content than at 20 kg P ha^{-1} in the 2015/16 growing season. Intercropping x P x season interaction was significant for percent glucose content in the storage root (P<0.05) (Table 6.1).



SP-SB-sweetpotato-soybean, SP-GN-SB-sweetpotato-soybean-groundnut-SP-GN-sweetpotato-groundnut, SOLE SP-sole sweetpotato,
Lines indicated with the same letter do not differ significantly at P=0.05.

Figure 6.3: Effect of intercropping sweetpotato and groundnut at different P levels on percent glucose content in sweetpotato storage roots grown at Umbeluzi research station in 2013/14, 2014/15 and 2015/16 growing seasons.

6.3.5 Percent starch content in sweetpotato storage roots

There was no significant difference in starch content between 0 and 20 kg P ha^{-1} in the 2015/16 growing season but in the 2013/14 and 2014/15 growing season, percent starch content was significantly higher at 20 than at 0 kg P ha^{-1} (P=0001) (Table 6.2). There was no significant difference in starch content between 20 kg P ha^{-1} and 40 kg P ha^{-1} in 2015/16 growing season but in the 2013/14 and 2014/15 growing seasons there was a significantly higher starch content at 40 kg P ha^{-1} than at 20 kg P ha^{-1} (P=0001) (Table 6.2). There was a significantly higher percent starch content at 40 kg P ha^{-1} than 0 kg P ha^{-1} in all growing seasons with 13.5 %, 16.2 % and 4 % more starch at 40 than at 0 kg P ha^{-1} in 2013/14, 2014/15 and 2015/16 growing seasons respectively (P=0001) (Table 6.2). There was a significantly higher percent starch content in 2015/16 compared to all other growing seasons (P=0.05) (Table 6.2). The highest percent starch content of 69.4 % was obtained in 2015/16 growing season at 40 kg P ha^{-1} (Table 6.2). Phosphorus x season interaction was significant for percent starch content in the sweetpotato storage roots (P=0001) (Table 6.1).

Table 6.2. Effect of P on percent starch content in sweetpotato storage root yield during 2013/14, 2014/15 and 2015/16 growing seasons

P x season	**Percent starch content**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	56.1^{e}	54.3^{f}	66.7^{b}	**59.0**
P20	59.7^{d}	59.9^{d}	68.4^{ab}	**62.7**
P40	63.7^{c}	63.1^{c}	69.4^{a}	**65.4**
Mean	**59.8**	**59.1**	**68.2**	**62.4**
% CV	**3.3**			
P x season LSD$_{0.05}$	**1.7**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

Percent starch content in the sweetpotato storage roots was affected by intercropping (P=0.0001) (Table 6.1). Sweetpotato- groundnut intercropping and sole sweetpotato had 6 % and 6.3 % respectively higher percent starch content than sweetpotato- soybean intercropping (P=0.0001) (Table 6.3). Sweetpotato- groundnut- soybean intercropping system had significantly higher percent starch content compared to sweetpotato- soybean (P=0001) (Table 6.3).

Table 6.3: Effect of intercropping on percent starch content in sweetpotato storage roots

Intercropping	Percent starch content
Sole sweetpotato	64.0^{a}
Sweetpotato- groundnut	63.8^{a}
Sweetpotato- soybean	60.2^{c}
Sweetpotato- groundnut- soybean	61.4^{b}
Mean	**62.4**
% CV	**3.3**
$LSD_{0.05}$	**1.1**

Means with at least a common letter are not significantly different, $LSD_{0.05}$

6.3.6 Percent fructose content

There was a significantly higher percent fructose content at 0 kg P ha^{-1} than at 20 kg P ha^{-1} in 2014/15 but there was no significant difference in percent fructose content between 0 and 20 kg P ha^{-1} in the 2013/14 and 2015/16 growing seasons (P=0.0001) (Table 6.4). Percent fructose content was significantly lower at 40 kg P ha^{-1}in 2013/14 and 2015/16 than at 0 kg P ha^{-1} (P=0.00011) (Table 6.4). There was no significant difference in percent fructose content between 20 and 40 kg P ha^{-1} in the 2013/14 and 2015/16 growing seasons but percent fructose content was significantly higher at 40 than at 20 kg P ha^{-1} in the 2014/15 growing seasons (P=0.00011) (Table 6.4). Phosphorus x season was significant for percent fructose content in sweetpotato storage roots (P=0.00011).

Table 6.4: Effect of P on percent fructose content in sweetpotato storage roots during 2013/14, 2014/15 and 2015/16 growing season

P x season	**Percent fructose**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	3.6^{cd}	4.5^{ab}	3.2^{de}	**3.8**
P20	3.5^{d}	4.1^{cd}	3.1^{de}	**3.6**
P40	3.3^{de}	5.0^{a}	2.9^{e}	**3.7**
Mean	**35**	**4.5**	**3.1**	**3.9**
% CV	**16.6**			
P x season $LSD_{0.05}$	**0.5**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

6.3.7 Significance of F values

Summary of significant effects (F values) of intercropping, P levels and growing seasons as well as their interactions on β-carotene (mg $100g^{-1}$ DW), Fe (mg $100g^{-1}$ DW) and Zn (mg $100g^{-1}$DW) in the sweetpotato storage roots grown at Umbeluzi research station in Mozambique in the 2013/14, 2014/15 and 2015/16 growing seasons are shown in table 6.5. Both Zn content and Zn yield were significantly affected by intercropping x P x season interaction. However, β-carotene yield (kg ha^{-1} DW), Fe (mg $100g^{-1}$ DW) and Fe yield (kg ha^{-1} DW) were significantly affected by intercropping x season and P x season interactions (Table 6.5).

Table 6.5: Significance of F values from analysis of variance done on nutrition parameters in the sweetpotato storage roots

Source of variation	β-carotene (mg $100g^{-1}$ DW)	β-carotene yield (kg ha^{-1} DW)	Fe (mg $100g^{-1}$ DW)	Fe yield (kg ha^{-1} DW)	Zn (mg $100g^{-1}$DW)	Zn yield (kg ha^{-1} DW)
I	ns	***	ns	***	*	***
P	ns	***	ns	***	ns	***
S	***	***	ns	***	***	***
I x P	ns	***	***	ns	ns	***
I x S	ns	*	***	***	ns	*
P x S	***	***	*	***	*	ns
I x P x S	ns	ns	ns	ns	*	**

*, *** Significant at P≤0.05, P≤0.001 respectively, ns denotes non significance at P≤0.05.
I-intercropping, P-phosphorus S- season, I x P-intercropping x Phosphorus, I x S-intercropping x season, I xP x S-intercropping x Phosphorus x season interaction.

6.3.8 β- carotene in the sweetpotato storage roots

There was no significant difference in β- carotene content in storage roots between 20 and 40 kg P ha^{-1} in the 2014/15 and 2015/16 growing seasons but in 2013/14 β- carotene content in the sweetpotato storage roots was significantly higher at 20 than at 40 kg P ha^{-1} (P=0.001) (Table 6.6). There was no significant difference in β- carotene content in the storage roots between 0 kg P ha^{-1} and 20 kg P ha^{-1} in all the growing seasons (P>0.05)(Table 6.6).

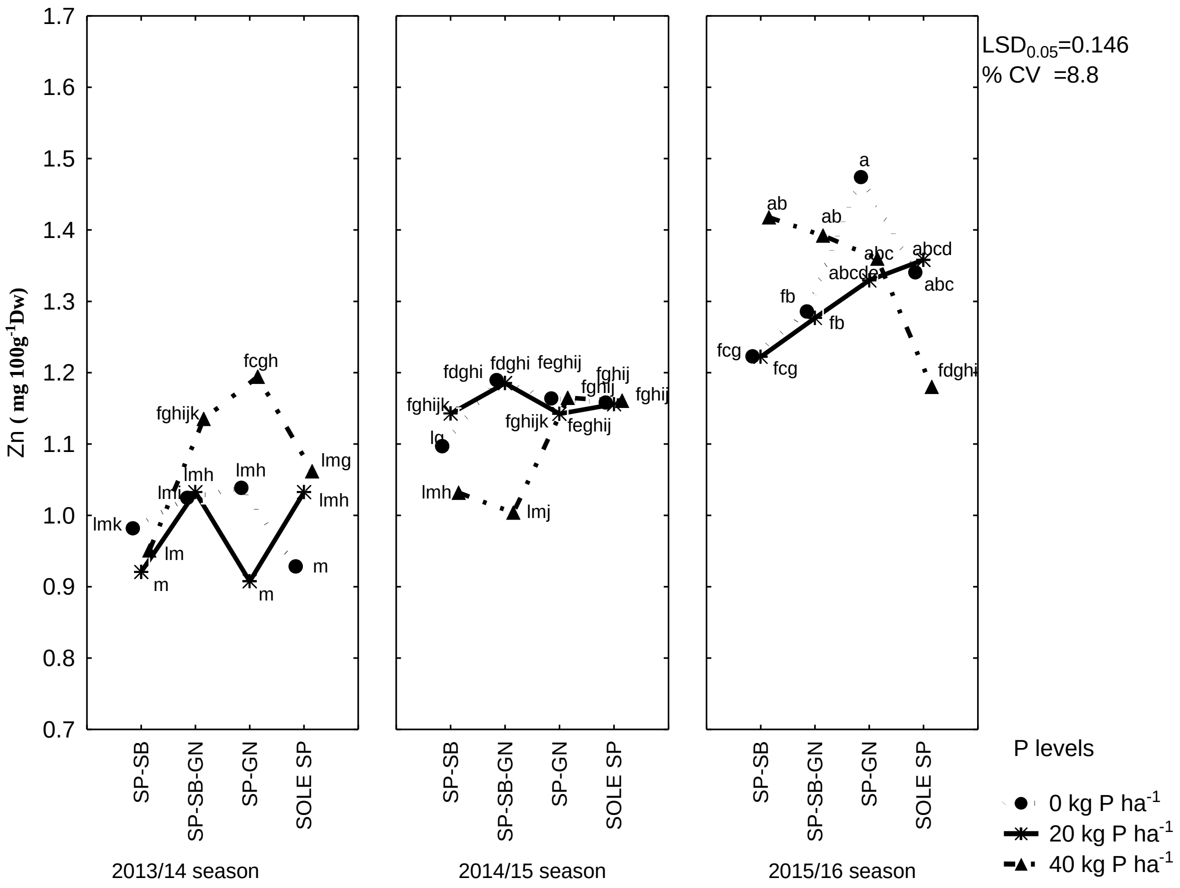
Table 6.6: Effect of P on β- carotene (mg $100g^{-1}$ DW) in the sweetpotato storage roots during 2013/14, 2014/15 and 2015/16 growing seasons

P x season	**β- carotene (mg $100g^{-1}$ DW)**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	22.1^{cd}	23.5^{bc}	27.7^{a}	**24.4**
P20	24.1^{bc}	25.0^{ab}	27.2^{a}	**25.4**
P40	20.1^{d}	26.5^{a}	27.8^{a}	**24.8**
Mean	**22.1**	**25.0**	**27.6**	**27.6**
% CV	**10.6**			
P x season $LSD_{0.05}$	**2.2**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

6.3.9 Zinc content in the sweetpotato storage roots

Sweetpotato- soybean and sweetpotato- groundnut at 0 kg P ha^{-1} had no significant difference in Zn content in the 2013/14 growing season but in the 2015/16 growing season, sweetpotato-groundnut had significantly higher Zn content in the sweetpotato storage roots than in sweetpotato-soybean at the same P level (P=0.033) (Fig 6.4). Sweetpotato- soybean intercropping and sole sweetpotato had no significant difference in Zn content at 40 kg P ha^{-1} in 2013/14 growing season but in 2015/16 growing season sweetpotato-soybean had a significantly higher Zn content in the sweetpotato storage root at 40 kg P ha^{-1} than roots from the sole sweetpotato cropping system (P=0.033) (Fig 6.4). Sweetpotato- legume intercropping resulted in a significantly higher Zn content in the 2015/16 than 2013/14 growing seasons at 0 and 20 kg P ha^{-1} (P=0.033) (Fig 6.4). Sweetpotato- groundnut intercropping at 40 kg P ha^{-1} had a significantly higher Zn content in sweetpotato storage roots than sole sweetpotato in the 2015/16 growing seasons (Fig 6.4). Intercropping x P x season was significant for Zn content in sweetpotato storage roots (P=0.033) (Table 6.5).



SP-SB-sweetpotato-soybean, SP-SB-GN-sweetpotato-soybean-groundnut, SP-GN-sweetpotato-groundnut, SOLE SP-sole sweetpotato.
Lines indicated with the same letter do not differ significantly at P=0.05.

Figure 6.4. Effect of intercropping sweetpotato and groundnut at different P levels on zinc content in sweetpotato storage roots grown at Umbeluzi research station in 2013/14, 2014/15 and 2015/16 growing seasons

There was no significant difference in Zn content in the sweetpotato storage roots between 0 and 20 kg P ha^{-1} in all treatments in all growing seasons (P>0.05) (Fig 6.4).

6.3.10 Iron content in sweetpotato storage roots

Sweetpotato- groundnut intercropping had a significantly higher Fe content in the sweetpotato storage roots at 0 kg P ha^{-1} than sole sweetpotato but the two cropping systems had no significant differences in Fe content in the sweetpotato storage roots between 20 and 40 kg p ha^{-1} (P<0.001) (Table 6.7). Sweetpotato- groundnut intercropping had 13.7 % higher Fe content than sole sweetpotato at 0 kg P ha^{-1}. Sweetpotato- soybean had no significant difference in Fe content in the storage roots with sole sweetpotato at 0 kg P ha^{-1} but at 20 kg P ha^{-1}, sole sweetpotato had a significantly higher Fe content in the sweetpotato storage roots than sweetpotato- soybean. Sweetpotato- soybean intercropping had significantly higher Fe content in the storage roots than sole sweetpotato at 40 kg P ha^{-1} (P<0.001) (Table 6.7). There was an 18.5 % decline in Fe content by increasing P from 0 to 40 kg P ha^{-1} in sweetpotato- groundnut intercropping (P<0.001) (Table 6.7). Intercropping x P interaction was significant for Fe content in sweetpotato storage roots (P<0.001) (Table 6.5).

Table 6.7: Effect of intercropping sweetpotato with groundnut and soybean at three P levels on iron content (mg 100g^{-1} DW) in the sweetpotato storage root

Intercropping x P	**Fe content (mg 100g^{-1} DW)**			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole sweetpotato	1.75^{bc}	1.83^{b}	1.60^{c}	**1.73**
Sweetpotato- groundnut	1.99^{a}	1.74^{bc}	1.68^{bc}	**1.80**
Sweetpotato- soybean	1.62^{c}	1.17^{d}	1.83^{b}	**1.54**
Sweetpotato- groundnut- soybean	1.75^{bc}	1.71^{bc}	1.65^{c}	**1.70**
Mean	**1.78**	**1.61**	**1.69**	**1.69**
% CV	**9.2**			
Intercropping x P LSD$_{0.05}$	**0.15**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

Sweetpotato- groundnut intercropping resulted in a significantly higher Fe content (2.01mg 100g-^{1} DW) in sweetpotato storage roots than sole sweetpotato (1.75 mg 100g^{-1} DW) by the end of the 2015/16 growing season but the two cropping systems had no significant difference in Fe content in the storage roots in the 2013/14 and 2014/15 growing seasons (P=0.0001) (Table 6.8). There was no significant difference in Fe content in the storage roots between sweetpotato- soybean and sweet-groundnut in the 2013/14 and 2014/15 growing seasons but sweetpotato- groundnut had significantly higher Fe content in the storage roots (2.01 mg 100g^{-1} DW) than in sweetpotato-soybean intercropping (1.64mg 100g^{-1} DW) in the 2015/16 growing season (P=0.0001) (Table 6.8). Sweetpotato- soybean intercropping had a significantly higher Fe content in the storage roots compared to sweetpotato- groundnut- soybean intercropping in the 2013/14 growing season but the two had no significant difference in Fe content in the storage roots in 2014/15 and 2015/16 growing seasons (P=0.0001) (Table 6.8). Intercropping x season interaction was significant for Fe content in sweetpotato storage roots (P=0001) (Table 6.5).

Table 6.8: Effect of intercropping sweetpotato, soybean and groundnut grown at Umbeluzi research station on iron content (mg $100g^{-1}$ DW) in sweetpotato storage roots in 2013/14, 2014/15 and 2015/16 growing seasons

Intercropping x season	**Fe content (mg $100g^{-1}$ DW) in sweetpotato storage root**			
	Growing seasons			
Intercropping	**2013/14**	**2014/15**	**2015/16**	**Mean**
Sole sweetpotato	1.70^{bc}	1.74^{bc}	1.75^{bc}	**1.73**
Sweetpotato-groundnut	1.70^{bc}	1.71^{bc}	2.01^{a}	**1.81**
Sweetpotato-soybean	1.8^{b}	1.72^{bc}	1.64^{c}	**1.72**
Sweetpotato-groundnut- soybean	1.60^{c}	1.80^{b}	1.73^{bc}	**1.71**
Mean	**1.70**	**1.74**	**1.78**	**1.74**
% CV	**9.2**			
Intercropping x season LSD $_{0.05}$	**0.15**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

There was no significant difference in Fe content between 20 and 40 kg P ha^{-1} in 2013/14 and 2015/16 but there was significantly higher Fe content at 20 than at 40 kg P ha^{-1} in the 2014/15 growing season (P=0.03) (Table 6.9). There was a significantly higher Fe content in the 2015/16 than 2013/14 growing seasons at 0 and 40 kg P ha^{-1} with a 10.7 % increase in Fe content from the 2013/14 to 2015/16 seasons at 0 kg P ha^{-1} (P=0.03) (Table 6.9) . Interaction of P x season was significant for Fe content in the sweetpotato storage roots (P=0.03) (Table 6.5).

Table 6.9. Effect of P on iron content (mg $100g^{-1}$ DW) in sweetpotato storage roots grown at Umbeluzi research station during 2013/14, 2014/15 and 2015/16 growing seasons

P x season	**Fe content (mg $100g^{-1}$ DW)**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	1.69^{bcd}	1.78^{abc}	1.87^{a}	1.78
P20	1.76^{abcd}	1.80^{ab}	1.69^{bcd}	1.75
P40	1.63^{d}	1.65^{cd}	1.79^{ab}	1.69
Mean	**1.69**	**1.74**	**1.78**	**1.74**
% CV	**9.2**			
P x season $LSD_{0.05}$	**0.13**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

6.3.11 Correlations

There was a significant and positive correlation between percent starch content and percent dry matter content in sweetpotato storage roots ($P<0.05$) (Table 6.10). β- carotene content had a significant and positive correlation with Fe, percent glucose and percent starch content ($P<0.05$) (Table 6.10). However, β-carotene content had a negative and non-significant correlation with percent dry matter.

Table 6.10: Correlation matrices of studied parameters in sweetpotato storage roots at Umbeluzi research station in Mozambique.

	% Dry matter content	**β- carotene content**	**Fe content**	**Zn content**	**% Glucose**	**% Starch**
% Dry matter content	1.000000					
β- carotene content	-0.020697	1.000000				
Fe content	-0.157139	0.207593*	1.000000			
Zn content	0.079876	0.084714	0.005728	1.000000		
% Glucose	0.070516	0.352693*	0.129775	0.006972	1.000000	
% Starch	0.432766*	0.341695*	0.020739	0.159110	0.047928	1.000000

* Significant at $P<0.05$

6.3.12 Multiple regression analysis

Regression analysis showed that β- Carotene content and Zn content in sweetpotato storage roots had a significant and positive correlation with total storage root yield (R^2 =0.311122008)(Table 6.11). In the same model Fe content in storage root yield had a significant negative correlation with total storage root yield in sweetpotato (Table 6.11).

Table 6.11: Multiple regression analysis of storage root yield, β- Carotene, Fe and Zn in sweetpotato

Regression Summary for Dependent Variable: Yield R=0.57491884 R²= 0.33053167 Adjusted R²= 0.31122008 F(3,104)=17.116 p<.00001						
	b *	Std Error b*	b	Std Error b	T(104)	P value
β- Carotene	0.203393*	0.087586	0.30989*	0.133445	2.32221	0.022170
Fe	-0.205738*	0.089843	-5.38082*	2.349745	-2.28996	0.024043
Zn	0.525172***	0.095885	16.73559	3.055565	5.47709	0.00001

6.3.13 Micronutrient yield in sweetpotato-legume intercropping systems

β- Carotene, Zn, and Fe yield as influenced by sweetpotato legume intercropping at three P levels is presented in sections 6.5.13.1 to 6.5.13.3.

6.3.13.1 β- carotene yield in sweetpotato-legume intercropping system

Sweetpotato- groundnut intercropping had a significantly higher β- carotene yield than in sole sweetpotato at all P levels (P=0.007) (Table 6.12). There was a 38.4 %, 54.3 % and 49.1 % higher β- carotene yield in sweetpotato- groundnut intercropping than sole sweetpotato at 0, 20 and 40 kg P ha^{-1} respectively (P=0.007) (Table 6.12) . There was no significant difference between 20 and 40 kg ha^{-1} on sweetpotato- groundnut intercropping (P>0.05) (Table 6.12). Sweetpotato- groundnut- soybean and sweetpotato- groundnut intercropping had no significant difference at 0 and 20 kg P ha^{-1} but sweetpotato- groundnut at 40 kg P ha^{-1} had a significantly higher β- carotene yield than sweetpotato- groundnut- soybean intercropping system (P=0.007) (Table 6.12) . Sweetpotato- soybean and sweetpotato- soybean- groundnut intercropping had a significantly higher β- carotene yield at 20 kg P ha^{-1} than sole sweetpotato but the two had no significant difference in β- carotene yield with sole sweetpotato at 40 kg P ha^{-1} (Table 6.12). Intercropping x P interaction was significant for β- carotene yield (P=0.007) (Table 6.5).

Table 6.12. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on β- carotene yield (kg ha^{-1}DW)

Intercropping x P	**β- carotene yield (kg ha^{-1}DW)**			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole sweetpotato	0.73^{e}	0.92^{d}	1.06^{cd}	**0.9**
Sweetpotato- groundnut	1.01^{cd}	1.42^{ab}	1.58^{a}	**1.34**
Sweetpotato- soybean	0.75^{de}	1.12^{c}	1.02^{cd}	**0.96**
Sweetpotato - groundnut- soybean	0.98^{cd}	1.36^{b}	1.11^{c}	**1.15**
Mean	**0.87**	**1.21**	**1.19**	
% CV	**18.0**			
Intercropping x P LSD$_{0.05}$	**0.18**			

Means with at least a common letter are not significantly different, LSD$_{0.05}$

Sweetpotato- groundnut intercropping had a significantly higher β- carotene yield in the 2013/14 and 2015/16 compared to sweetpotato- groundnut- soybean intercropping but in the 2014/15 growing season there was no significant difference between the two cropping systems (P=0.012) (Table 6.12). Sweetpotato- soybean had a significantly higher β- carotene yield in the 2013/14 growing season but in the 2014/15 and 2015/16 growing seasons there was no significant difference between the two treatments (Table 6.13). Intercropping x season interaction was significant for β- carotene yield (P=0.012) (Table 6.5).

Table 6.13: Effect of intercropping sweetpotato, groundnut and soybean on β- carotene yield (kg ha^{-1} DW) over three growing seasons

Intercropping x season	**β- Carotene yield (kg ha^{-1} DW)**			
	Growing seasons			
Intercropping	**2013/14**	**2014/15**	**2015/16**	**Mean**
Sole sweetpotato	0.61^{g}	0.71^{fg}	1.39^{c}	**0.90**
Sweetpotato-groundnut	1.12^{d}	0.94^{de}	1.95^{a}	**1.34**
Sweetpotato-soybean	0.87^{ef}	0.65^{g}	1.37^{c}	**0.96**
Sweetpotato- groundnut- soybean	0.85^{ef}	0.92^{e}	1.67^{b}	**1.15**
Mean	**0.86**	**0.81**	**1.60**	**1.09**
% CV	**18.0**			
Intercropping x season LSD $_{0.05}$	**0.18**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

There was a significantly higher β- carotene yield at 20 kg P ha^{-1} than 40 kg P ha^{-1} in the 2013/14 growing season but in the other two growing seasons there was no significant difference between the two P levels (P=0.006) (Table 6.14). Interaction of P x season was significant for β- carotene yield in sweetpotato (P=0.006) (Table 6.5).

Table 6.14: Effect of P on β- carotene yield over three growing seasons at Umbeluzi research station

P x season	**β- Carotene yield (kg ha^{-1} DW)**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	0.70^{de}	0.68^{e}	1.22^{b}	**0.87**
P20	1.03^{c}	0.85^{d}	1.73^{a}	**1.2**
P40	0.86^{d}	0.89d	1.83^{a}	**1.19**
Mean	**0.86**	**0.81**	**1.59**	**1.09**
% CV	**18**			
P x season $LSD_{0.05}$	**0.16**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

6.3.13.2. Zinc yield in sweetpotato –legume intercropping system

There was a significantly higher Zn yield on sweetpotato- groundnut intercropping at 40 kg P ha^{-1} (46.3 % more) than sweetpotato- groundnut- soybean intercropping but at 0 and 20 kg P there was no significant difference between the two intercropping treatments (P=0.023) (Table 6.15). Sweetpotato- soybean intercropping and sole sweetpotato had a significantly lower Zn yield at 0 and 20 kg P ha^{-1} than sweetpotato- groundnut- soybean intercropping but the three intercropping combinations had no significant difference at 40 kg P ha^{-1} (P=0.023) (Table 6.15). Sweetpotato-groundnut intercropping had significantly higher Zn yield than sweetpotato-soybean and sole sweetpotato at 20 and 40 kg P ha^{-1} (P=0.023) (Table 6.15). Sweetpotato-groundnut at 20 and 40 kg P ha^{-1} had 32.7 % and 71.7 % more Zn yield than sweetpotato-soybean intercropping respectively. Sweetpotato-groundnut at 20 and 40 kg P ha^{-1} had 47.7 % and 58 % more Zn than sole sweetpotato respectively. Intercropping x P interaction was significant for Zn yield on a dry matter basis (P=0.023) (Table 6.5).

Table 6.15. Effect of intercropping sweetpotato, groundnut and soybean at three P levels on Zn yield at Umbeluzi research station

Intercropping x P	**Zn yield (kg ha^{-1} DW)**			
	P levels			
Intercropping	**P0**	**P20**	**P40**	**Mean**
Sole sweetpotato	0.043^{d}	0.044^{cd}	0.05^{cd}	**0.046**
Sweetpotato- groundnut	0.05^{cd}	0.065^{b}	0.079^{a}	**0.066**
Sweetpotato- soybean	0.033^{e}	0.049^{cd}	0.046^{cd}	**0.043**
Sweetpotato- groundnut- soybean	0.047^{cd}	0.06^{b}	0.055^{bc}	**0.054**
Mean	**0.043**	**0.055**	**0.058**	**0.052**
% CV	**18.7**			
Intercropping x P $LSD_{0.05}$	**0.009**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

There was a significantly higher Zn yield at 20 kg P ha^{-1} than at 0 kg P ha^{-1} in the 2013/14 and 215/16 growing seasons but no significant difference in Zn yield between the two P levels in the 2014/15 growing season (P=0.001) (6.16). There was a significantly higher Zn yield in the 2015/16 than both 2013/14 and 2014/15 growing seasons at all P levels (P=0.001) (6.16). P x season interaction was significant for Zn yield (P=0.001) (Table 6.5).

Table 6.16: Effect of P on Zn yield over three growing season at Umbeluzi research station

P x season	Zn yield (kg ha^{-1} DW)			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	0.031[e]	0.033[de]	0.060[b]	**0.041**
P20	0.041[cd]	0.04[cd]	0.082[a]	**0.054**
P40	0.047[c]	0.037[de]	0.088[a]	**0.057**
Mean	**0.04**	**0.037**	**0.077**	**0.051**
% CV	**18.7**			
P x season $LSD_{0.05}$	**0.008**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

6.3.13.3. Fe yield in sweetpotato-legume intercropping system

Intercropping x season interaction was significant for Fe yield (P=0.0001) (Table 6.5). Sweetpotato-soybean had significantly higher Fe yield (0.07 mg $100g^{-1}$) in than sole sweetpotato (0.05mg $100g^{-1}$) in the 2013/14 growing season but no significant difference in Fe yield was noted in the 2014/15 and 2015/16 growing seasons (P=0.0001) (Table 6.17). Sweetpotato- groundnut had a significantly higher Fe yield than sweetpotato-soybean-groundnut in the 2013/14 and 2015/16 growing seasons but there was no significant difference between these two cropping systems in the 2014/15 growing season (P=0.0001) Table 6.17).

Table 6.17: Effect of intercropping on Fe yield over three growing seasons at Umbeluzi research station

Intercropping x season	**Fe yield kg ha^{-1} DW**			
	Growing seasons			
Intercropping	**2013/14**	**2014/15**	**2015/16**	**Mean**
Sole sweetpotato	0.05^{f}	0.05^{f}	0.09^{bc}	**0.06**
Sweetpotato-groundnut	0.09^{bc}	0.06^{ef}	0.14^{a}	**0.1**
Sweetpotato-soybean	0.07^{de}	0.05^{f}	0.08^{cd}	**0.07**
Sweetpotato- groundnut- soybean	0.06^{ef}	0.07^{de}	0.1^{b}	**0.08**
Mean	**0.07**	**0.06**	**0.1**	**0.08**
% CV	**17.9**			
Intercropping x season LSD $_{0.05}$	**0.013**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

There was a significantly lower Fe yield in 2014/15 than 2013/14 at 20 and 40 kg P ha^{-1} but there was no difference in Fe yield at 0 kg P ha^{-1} in the same growing season (P=0.008) (Table 6.18). Phosphorus x season interaction was significant for Fe yield in sweetpotato (P=0.008) (Table 6.5).

Table 6.18: Effect of P on Fe yield kg yield over three growing seasons at Umbeluzi research station

P x season	**Fe yield (kg ha^{-1}DW)**			
	Growing seasons			
P levels	**2013/14**	**2014/15**	**2015/16**	**Mean**
P0	0.05^{d}	0.05^{dd}	0.08^{b}	**0.6**
P20	0.07^{bc}	0.06^{cd}	0.11^{a}	**0.8**
P40	0.07^{bc}	0.05^{d}	0.12^{a}	**0.8**
Mean	**0.063**	**0.053**	**0.1**	**0.7**
% CV	**17.9**			
P x season LSD$_{0.05}$	**0.011**			

Means with at least a common letter are not significantly different, $LSD_{0.05}$

6.4 Discussion

Intercropping and incorporation of crop residues is an effective way of improving sweetpotato nutritional quality. In all growing seasons percent dry matter was significantly higher in sole sweetpotato at 40 kg P ha^{-1} than any other intercropping combination involving soybeans. Shading of sweetpotato by soybean crop could have interfered with photosynthesis resulting in low dry matter in storage roots under sweetpotato- soybean intercropping. High P rates of 40 kg ha^{-1} may have increased photosynthetic rates and other metabolic process that culminated in high dry matter content in the storage roots as pointed out by El-Sayed et al. (2011).

Highest glucose content of 7.6 % was observed in sole sweetpotato at 40 kg P ha^{-1}. This result show that it is probable that P fertiliser application is necessary for the synthesis of organic compounds including glucose. Increasing P levels from 0 to 40 kg ha^{-1} increased starch content in sweetpotato storage roots. This result may be explained on the basis of the necessity of available P as a plant nutrient that is an essential constituent of many organic compounds that are vital for metabolic processes such as photosynthesis (Abdel-Razzak et al. 2013). The results of the current study are in agreement with those of El-Morsy et al. (2002), Hassan et al. (2005) and El-Sayed et al. (2011) who pointed out that an increase in the rate of applied P fertilizer from 15 to 60 kg P_2O_5 ha^{-1} resulted in an increase in total sugars, carbohydrates, and starch contents in sweetpotato storage roots. Therefore farmers are recommended to apply 40 kg P ha^{-1} in sweetpotato for increased percent dry matter and sugars.

β- Carotene content in the sweetpotato storage roots was higher in the 2015/16 growing seasons compared to the 2013/14 growing seasons at all P levels. Lower total rainfall from the 2013/14 to 2014/15 growing seasons could probably have contributed towards higher total β-carotene content in sweetpotato, compared to that produced in 2013/14 growing seasons (Table 3.1). Laurie et al. (2012) working in villages without irrigation and at a research station with optimum irrigation observed that irregular water applications at the rural village contributed towards higher total β-carotene content in sweetpotato. A further reduction in total rainfall in 2015/16 compared to 2013/14 growing seasons could have encouraged β- carotene synthesis in sweetpotato. These results are important for effective irrigation management practices that would allow farmers to maximise the potential β- carotene content in the new OFSP varieties. The results indicate that even if a sweetpotato variety has a high potential for high β- carotene content, its synthesis is affected by other environmental conditions such as rainfall. Farmers therefore should manipulate the cropping environment through irrigation management to ensure maximum β- carotene biosynthesis with the view of improving household nutritional status.

Sweetpotato- groundnut had significantly higher β- carotene yield than sole sweetpotato and sweetpotato- soybean intercropping at 20 and 40 kg P ha^{-1} and in all growing seasons. In addition, β-carotene yield was significantly higher at 20 than at 0 kg P ha^{-1}, suggesting that sweetpotato-groundnut intercropping at 20 kg P ha^{-1} contributes to higher β- carotene yield in sweetpotato.

Zinc content in the sweetpotato storage roots increased by 29.4 % from the 2013/14 to 2015/16 growing seasons. Sweetpotato- groundnut intercropping at 40 kg P ha^{-1} increased Zn content and Zn yield in sweetpotato. As reported in Chapter 3 of this thesis, soil pH decreased in the 2014/15 growing season in soils cultivated with groundnut. Possibly, proton extrusion from groundnut in the rhizosphere could have reduced soil pH that contributed to Zn availability in the soil that was then taken up by sweetpotato in the 2014/15 growing season (Srinivasarao and Sudha 2013). Additionally, increased inputs of plants residue and their incorporation into the soil, at the end of the 2013/14 and 2014/15 growing season could have probably increased exchangeable and organic fractions of Zn and decreased oxide fractions of Zn in soil because of reducing conditions to enhance Zn availability (Srinivasarao and

Sudha, 2013). Similar results were reported by Kumar and Babel (2010), Habiby at al. (2014), Srinivasarao and Sudha (2013) and in which they noted significant DTPA extractable Zn in the soil after incorporation of all preceding crop residues in the soil. Crop management practices such as intercropping with legumes and incorporation crop residues into the soil should be encouraged so that farmers accrue the benefits of increased Fe and Zn content in the sweetpotato storage roots thereby contributing in fighting hidden hunger of micronutrient deficiency in Mozambique.

Fertilization by P had no influence on Fe availability in the sweetpotato storage root. Sweetpotato-groundnut intercropping increased Fe content in the sweetpotato storage roots by 18.2 % from the 2013/14 to 2015/16 growing seasons. In addition, Fe yield was significantly higher on sweetpotato- groundnut than in sole sweetpotato in the 2015/16 growing season. Increased Fe content in the storage roots could have been caused by increased availability of Fe in the soil probably resulting from organic matter emanating from incorporated crop residues in the 2013/14 and 2014/15 growing seasons or from soil acidification from legumes. Organic matter improves iron availability due to chelation, which increases iron solubility. Higher plants have developed strategies that help them increase iron availability in soils in which legume species acidify the rhizosphere root zone through proton (H^+) extrusion in response to iron deficiency, increasing Fe^{3+} 'chelates' solubility and resulting in reduction by a ferric reductase to ferrous iron which can be taken up by plants (Robinson et al. 1999, Alcaniz et al. 2005). Results from the present study are fully supported by Singh et al. (2005) who reported that application of acid producing amendments on soils could decrease soil pH and consequently increase plant-available Fe and Zn. Farmers could increase Fe content in sweetpotato through sweetpotato- groundnut intercropping followed by crop residue incorporation into the soil with the view of improving sweetpotato storage roots nutritional quality.

6.5 Conclusion

The study show that P is an important element that influence dry matter content, glucose, starch and sucrose accumulation in sweetpotato since there is evidence that increasing P fertilizer resulted in an increase in these sugars. Legume intercropping did not improve these carbohydrates. Sweetpotato- legume intercropping and incorporation of crop residues into the soil at the end of each growing seasons increased Zn and Fe content in sweetpotato storage roots. Therefore, sweetpotato-legume intercropping and incorporation of crop residues into the soil is an important sweetpotato management practice for nutrition as it increases availability of Zn and Fe in the soil that will subsequently be absorbed by sweetpotato for nutritional benefits. β- carotene synthesis in sweetpotato was not affected by both legume intercropping and P levels in this study. However, seasonal effect was noted to play a role in β- carotene synthesis in sweetpotatoes.

Farmers in Mozambique are therefore recommended to adopt the technology of sweetpotato- sweetpotato intercropping and incorporation of crop residues in their farms as this would assist in improving Fe and Zn availability in OFSP and hence contribute to fighting micronutrient deficiency. In addition, OFSP farmers in Mozambique may consider manipulating the environment through reduced irrigation with the view of increasing β-carotene biosynthesis since this study has clearly revealed that low rainfall improves β-carotene content in OFSP. This may also contribute to a reduction in vitamin A deficiency that is currently very high in Mozambique.

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Chapter 7 : General discussion

7. 1 Main findings

Variance has always existed between researcher trials and farmer managed fields. The difference is almost 100 % for sweetpotato in Mozambique where mean production for improved OFSP varieties is about 15 t ha^{-1} (Andrade et al. 2016) and 7 t ha^{-1} (Andrade et al. 2016, FAO 2015) under researcher and farmer's fields respectively. Reasons for the wide gap can be traced to agronomic management, climate change and continuous soil degradation.

In the past sweetpotato was considered a woman crop and likewise did not receive much research attention like cereals or grain legumes. In Mozambique, as well, the extension agents do not have adequate agronomic information on sweetpotato production especially on issues to do with crop fertilisation and the necessary intercropping and rotation systems. Mozambique farmers are resource poor and cannot afford to purchase artificial fertilisers. In addition, artificial fertilisers are not always available and accessible – due to transport logistics/political instability in Mozambique.

Another viable option is to do intercropping with legume crops as a way of improving yields and restoring soil fertility. In the present study, total N increased and mineral N improved through N fixation by including groundnut and soybean in the sweetpotato intercropping system. The results are similar to reports by Vitousek et al. (1997), Shoko et al. (2014), and Russelle and Birr (2005) who reported the role of legumes in N fixation. Farmers are encouraged to intercrop with legumes for soil fertility improvement. Total and Olsen P also increased in sweetpotato-groundnut and in sweetpotato-soybean intercropping systems. Any system that increase P in the soil should be capitalised by farmers because P is one of the essential elements that is most scarce due to easy fixation and depletion in the natural reserves.

Incorporation of crop residues and sweetpotato legume intercropping increased soil CEC. Thus one of the ways to increase soil CEC is the incorporation of crop residues into the soil as demonstrated in this study, instead of burning - a common practice by smallholder farmers (Hulugalle and Palada 1990, Hulugalle and Maurya 1991). High CEC is an important measure of soil fertility and prevents leaching of cations such as K^+ Mg^2+ and other cations that are important in crop production (CUCE 2007, Massawe et al. 2016).

Sole sweetpotato production reduced total K in the soil compared to sweetpotato-legume treatments. Therefore farmers should be discouraged from sole sweetpotato production as it rapidly deplete K. The nutrient K is important for high sweetpotato yield as observed by Njoku et al. (2001) who found that sweetpotato demands as high as 160 kg K ha^{-1} for storage root formation and high yields through the formation of large sized storage roots (IFA 1991, Njoku et al. 2001, Degras 2003, Uwah et al. 2013). Incorporation of crop residues also helps in K recycling (Lupwiya 2005).

In the study total P was lower at the end of the 2013/14 growing season at 40 kg P ha^{-1} in plots with sweetpotato- soybean and sweetpotato- groundnut intercropping than sole sweetpotato probably because legume roots secreted organic acids or H^+ ions that facilitated P mobility (Xia et al. 2013). Inclusion of legume in sweetpotato cropping system reduce soil pH and this may be important for farmers in calcareous soils where some important plant nutrients such as P, Fe and Zn are made unavailable due to high pH (Prasad and Power 1997, McCauley 2009). In this case inclusion of legumes can be a cheap pH amendment strategy that also assist in making micronutrients such as Zn and Fe available for uptake by the sweetpotato crop (Kumar et al. 1998, Wang et al. 2014).

Intercropping and P application influenced the growth characteristics of sweetpotato. Fresh root mass $plant^{-1}$ and numbers of leaves plant $^{-1}$ increased at 40 kg P ha^{-1} indicating that P is important for sweetpotato vegetative growth especially leaves and fresh roots. The leaves are a source of income for farmers where sweetpotato leaves are eaten as vegetables. These results are fully supported by Abdel-Razzak et al (2013) who reported that high P nutrition increase sweet potato leaf mass. The main stem length was 10 % higher in sweetpotato- soybean intercropping than in sole sweetpotato at 20 kg P ha^{-1} probably because sweetpotato was competing for solar radiation as reported by Ikeorgu et al. (1983), Orkwor (1990) and Maoneke et al. (1997). The longer main stems may be important for sweetpotato vine producers who want longer vines that serve as planting material. However, due to heavy shading from soybean the thin long vines might have problems of vigour but this requires further investigation.

In this study, the best intercropping combination was sweetpotato- groundnut mainly due to lack of shading effects of groundnut on sweetpotato. Intercropping benefits for the sweetpotato-groundnut intercropping at 20 kg P ha^{-1} were more total storage root yield and commercial storage root yield, number of storage roots plant^{-1}, higher harvest index than the sole sweetpotato crop and high land equivalent ratio of 1.6 on average. High P doses of 20 kg probably stimulated root formation for nutrient absorption resulting in increased yield compared to 0 kg P ha^{-1} treatment (Hassan et al. 2005). Intercrop between sweetpotato-soybean depressed sweet potato yield due to shading effects (Mwanga and Zamora 1988, Oswald et al. 1995). For maximum benefits in intercropping system farmers are recommended to plant crops of equal height and are discouraged from intercropping sweetpotato with soybean.

Application of 40 kg P ha^{-1} increased sugars and dry matter content of sweetpotato storage roots. The higher sugar levels observed at 40 kg P ha^{-1} emphasise the importance of P in photosynthesis and other metabolic processes involved in the synthesis of starch, glucose and fructose in sweetpotato as earlier observed by El-Sayed et al. (2011).

In the present study, Fe and Zn were largely influenced by the intercropping systems with subsequent incorporation of crop residues into the soil. There was more Fe and Zn resulting from sweetpotato-groundnut, sweetpotato-soybean and sweetpotato-soybean-groundnut intercropping system at the end of the 2015/16 growing season probably due to proton extrusion from legumes in the rhizosphere (Singh et al. 2005, Kumar and Babel 2010, Habiby at al. 2014). Farmers in Mozambique are recommended to intercrop sweetpotato with groundnut followed by incorporation of crop residues after each harvest so that they take advantage of the Fe and Zn benefits that were observed in the OFSP roots in this study.

In the current study, β- carotene was neither influenced by intercropping systems nor P fertilisation. This was not unusual though since Grüneberg et al. (2005) had indicated that nutritional quality traits are less affected by genotype x environment interactions. This could be good for producing OFSP sweetpotato under different intercropping systems without affecting the β- carotene. However, β- carotene content can to a certain extent be manipulated by managing soil water content.

7.2 Concluding remarks

Sweetpotato-groundnut intercropping and P application at 20 kg P ha^{-1} as well as incorporation of sweetpotato, groundnut and soybean crop residues is an effective approach to diversify farming systems, maximize the use of farmland, and provide numerous agroecosystems services, such as the maintenance of soil fertility, moisture conservation and increase farm productivity. The study has demonstrated sweetpotato yield, harvest index, commercial yield, land equivalence ratio and nutritional quality benefits resulting from sweetpotato- groundnut intercropping. Application of 20 kg P ha^{-1} is sufficient for high sweetpotato yield and number of leaves plant^{-1}. High number of sweetpotato leaves improve capture of solar radiation necessary for photosynthesis and hence improved growth and yield. In addition sweetpotato leaves are important for use as vegetables and can be a source of income for urban households in southern Mozambique.

7.3 Implications to sweetpotato production system

The results of this study demonstrated that intercropping sweetpotato with groundnut and incorporation of crop residues at harvest would improve micronutrients Zn and Fe in the soil that is taken up by sweetpotato and improve sweetpotato yield and nutritional quality particularly Zn and Fe. This may contribute in fighting "hidden hunger" of micronutrient deficiencies that is prevalent in Sub-Saharan Africa as well as ensuring food security through increased sweetpotato productivity. The cropping system would also improve sweetpotato leaves that are commercialised as vegetables in Mozambique. In addition, sweetpotato-groundnut intercropping and incorporation of residues assist in improving soil chemical properties that would benefit subsequent crops. Improved CEC in this cropping system would help prevent leaching of other essential nutrients necessary for plant growth.

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APPENDICES

Appendix 1: ANOVA Tables for Chapter 3: Influence of intercropping sweetpotato, groundnut and soybean on Soil chemical properties.

Soil percent total N

Source	SS	DF	MS	F	P
Intercropping	0.007580	6	0.001263	2.100	0.057677
P	0.002586	2	0.001293	2.149	0.120825
Season	0.188309	2	0.094155	156.537	0.000000
Intercropping x P	0.014627	12	0.001219	2.027	0.026911
Intercropping x season	0.038287	12	0.003191	5.304	0.000000
P x season	0.004826	4	0.001207	2.006	0.097625
Intercropping x P x season	0.024015	24	0.001001	1.664	0.038149
Error	0.075787	126	0.000601		

Soil percent mineral N

Source	SS	DF	MS	F	P
Intercropping	0.003331	6	0.000555	1.9079	0.084484
P	0.001166	2	0.000583	2.0031	0.139183
Season	0.066305	2	0.033153	113.9177	0.000000
Intercropping x P	0.007946	12	0.000662	2.2752	0.011955
Intercropping x season	0.006213	12	0.000518	1.7790	0.058430
P x season	0.002171	4	0.000543	1.8651	0.120631
Intercropping x P x season	0.010436	24	0.000435	1.4942	0.080987
Error	0.036669	126	0.000291		

Soil percent total P

Source	SS	DF	MS	F	P
Intercropping	25763	6	4294	1.156	0.334300
P	2035	2	1017	0.274	0.760864
Season	973716	2	486858	131.060	0.000000
Intercropping x P	42916	12	3576	0.963	0.487915
Intercropping x season	71928	12	5994	1.614	0.095851
P x season	6290	4	1572	0.423	0.791589
Intercropping x P x season	157953	24	6581	1.772	0.023086
Error	464347	125	3715		

Soil Olsen P

Source	SS	DF	MS	F	P
Intercropping	11.0172	6	1.8362	2.924	0.010517
P	1.0359	2	0.5180	0.825	0.440611
Season	106.9535	2	53.4768	85.170	0.000000
Intercropping x P	7.8449	12	0.6537	1.041	0.415844
Intercropping x season	16.1271	12	1.3439	2.140	0.018623
P x season	14.2715	4	3.5679	5.682	0.000308
Intercropping x P x season	26.6650	24	1.1110	1.770	0.023222
Error	79.1132	126	0.6279		

Soil CEC

Source	SS	DF	MS	F	P
Intercropping	446.7	6	74.5	2.956	0.009840
P	940.0	2	470.0	18.661	0.000000
Season	659.1	2	329.5	13.084	0.000007
Intercropping x P	1493.6	12	124.5	4.942	0.000001
Intercropping x season	163.6	12	13.6	0.541	0.884086
P x season	143.6	4	35.9	1.425	0.229422
Intercropping x P x season	296.4	24	12.3	0.490	0.977455
Error	3173.5	126	25.2		

Soil pH (H_2O)

Source	SS	DF	MS	F	P
Intercropping	2.805	6	0.467	19.7	0.000000
P	0.095	2	0.047	2.0	0.139063
Season	17.066	2	8.533	360.3	0.000000
Intercropping x P	0.400	12	0.033	1.4	0.170766
Intercropping x season	1.821	12	0.152	6.4	0.000000
P x season	0.366	4	0.092	3.9	0.005344
Intercropping x P x season	0.528	24	0.022	0.9	0.563241
Error	2.984	126	0.024		

Soil percent total K

Source	SS	DF	MS	F	P
Intercropping	22.849	6	3.808	2.418	0.030224
P	14.654	2	7.327	4.653	0.011231
Season	506.738	2	253.369	160.895	0.000000
Intercropping x P	20.322	12	1.693	1.075	0.386337
Intercropping x season	60.661	12	5.055	3.210	0.000485
P x season	8.415	4	2.104	1.336	0.260278
Intercropping x P x season	32.309	24	1.346	0.855	0.660981
Error	198.418	126	1.575		

Soil percent available K

Source	SS	DF	MS	F	P
Intercropping	0.07387	6	0.01231	1.81	0.103215
P	0.03296	2	0.01648	2.42	0.093411
Season	1.77377	2	0.88688	130.02	0.000000
Intercropping x P	0.15053	12	0.01254	1.84	0.048572
Intercropping x season	0.30282	12	0.02523	3.70	0.000087
P x season	0.08201	4	0.02050	3.01	0.020822
Intercropping x P x season	0.20257	24	0.00844	1.24	0.223280
Error	0.85943	126	0.00682		

Appendix 2: ANOVA Tables for chapter 4: Influence of P on sweetpotato, groundnut and soybean vegetative growth under monoculture and intercropping farming systems.

Sweetpotato main stem length

Source	SS	DF	MS	F	P
Intercropping	2197	3	732	19.51	0.000000
P	661	2	331	8.81	0.000377
Season	139	2	69	1.85	0.164716
Intercropping x P	987	6	165	4.38	0.000788
Intercropping x season	367	6	61	1.63	0.151652
P x season	2515	4	629	16.75	0.000000
Intercropping x P x season	1129	12	94	2.51	0.008238
Error	2702	72	38		

Sweetpotato number of leaves plant^{-1}

Source	SS	DF	MS	F	P
Intercropping	4213	3	1404	15.9	0.000000
P	129295	2	64648	730.7	0.000000
Season	4484	2	2242	25.3	0.000000
Intercropping x P	1287	6	214	2.4	0.034390
Intercropping x season	878	6	146	1.7	0.145025
P x season	747	4	187	2.1	0.088319
Intercropping x P x season	588	12	49	0.6	0.871379
Error	6370	72	88		

Sweetpotato stem diameter

Source	SS	DF	MS	F	P
Intercropping	0.19367	3	0.06456	44.55	0.000000
P	0.78041	2	0.39020	269.28	0.000000
Season	0.05182	2	0.02591	17.88	0.000000
Intercropping x P	0.04028	6	0.00671	4.63	0.000493
Intercropping x season	0.03309	6	0.00552	3.81	0.002379
P x season	0.00251	4	0.00063	0.43	0.784176
Intercropping x P x seasons	0.02909	12	0.00242	1.67	0.091153
Error	0.10433	72	0.00145		

Sweetpotato fresh root mass

Source	SS	DF	MS	F	P
Intercropping	479.7	3	159.9	41.19	0.000000
P	4256.2	2	2128.1	548.16	0.000000
Season	215.5	2	107.7	27.75	0.000000
Intercropping x P	73.2	6	12.2	3.14	0.008593
Intercropping x season	333.9	6	55.7	14.33	0.000000
P x season	28.9	4	7.2	1.86	0.126342
Intercropping x P x season	379.0	12	31.6	8.14	0.000000
Error	279.5	72	3.9		

Groundnut number of nodules plant^{-1}

Source	SS	DF	MS	F	P
Intercropping	173.21	3	57.74	13.410	0.000000
P	1278.02	2	639.01	148.415	0.000000
Season	40.35	2	20.18	4.686	0.012214
Intercropping x P	22.65	6	3.77	0.877	0.516440
Intercropping x season	25.43	6	4.24	0.984	0.442400
P x season	53.37	4	13.34	3.099	0.020650
Intercropping x P x season	24.63	12	2.05	0.477	0.922079
Error	310.00	72	4.31		

Number of days to first flowering in groundnut

Source	SS	DF	MS	F	P
Intercropping	274.92	3	91.64	76.13	0.000000
P	143.63	2	71.81	59.66	0.000000
Season	5.80	2	2.90	2.41	0.097238
Intercropping x P	4.44	6	0.74	0.62	0.717272
Intercropping x season	89.61	6	14.94	12.41	0.000000
P x season	4.98	4	1.25	1.03	0.395401
Intercropping x P x season	18.28	12	1.52	1.27	0.257962
Error	86.67	72	1.20		

Number of leaves plant^{-1} in groundnut

Source	SS	DF	MS	F	P
Intercropping	3717	3	1239	39.74	0.000000
P	5914	2	2957	94.85	0.000000
season	301	2	151	4.83	0.010718
Intercropping x P	94	6	16	0.50	0.806319
Intercropping x season	1377	6	229	7.36	0.000004
P x season	46	4	11	0.37	0.831721
Intercropping x P x season	103	12	9	0.28	0.991374
Error	2245	72	31		

Soybean plant height

Source	SS	DF	MS	F	P
Intercropping	395.7	3	131.9	6.69	0.000479
P	4093.5	2	2046.8	103.79	0.000000
season	197.8	2	98.9	5.02	0.009135
Intercropping x P	77.7	6	12.9	0.66	0.684687
Intercropping x season	36.0	6	6.0	0.30	0.932576
P x season	199.3	4	49.8	2.53	0.048004
Intercropping x P x season	270.1	12	22.5	1.14	0.341902
Error	1419.8	72	19.7		

Soybean number of nodules plant^{-1} in the first 10 cm

Source	SS	DF	MS	F	P
Intercropping	52.81	3	17.60	1.972	0.125760
P	561.17	2	280.58	31.435	0.000000
season	155.72	2	77.86	8.723	0.000405
Intercropping x P	129.80	6	21.63	2.424	0.034387
Intercropping x season	100.35	6	16.73	1.874	0.097058
P x season	105.94	4	26.49	2.967	0.025074
Intercropping x P x season	154.20	12	12.85	1.440	0.168376
Error	642.67	72	8.93		

Soybean stem diameter

Source	SS	DF	MS	F	P
Intercropping	0.00916	3	0.00305	3.27	0.025903
P	0.23889	2	0.11945	128.10	0.000000
Season	0.12478	2	0.06239	66.91	0.000000
Intercropping x P	0.01249	6	0.00208	2.23	0.049437
Intercropping x season	0.00685	6	0.00114	1.22	0.303948
P x season	0.05529	4	0.01382	14.83	0.000000
Intercropping x P x season	0.01612	12	0.00134	1.44	0.167842
Error	0.06713	72	0.00093		

Appendix 3. ANOVA Tables for chapter 5: Yield and yield components of sweetpotato, groundnut and soybean in monoculture and intercropping systems under different P levels.

Total storage root yield in sweetpotato

Source	SS	DF	MS	F	P
Intercropping	549.27	3	183.09	38.475	0.000000
P	227.91	2	113.96	23.948	0.000000
Season	1642.12	2	821.06	172.543	0.000000
Intercropping x P	122.49	6	20.42	4.290	0.000943
Intercropping x season	72.27	6	12.05	2.531	0.027961
P x season	87.34	4	21.84	4.589	0.002341
Intercropping x P x season	80.27	12	6.69	1.406	0.183426
Error	342.62	72	4.76		

Commercial storage root yield in sweetpotato

Source	SS	DF	MS	F	P
Intercropping	385.79	3	128.60	29.946	0.000000
P	179.98	2	89.99	20.956	0.000000
Season	1354.15	2	677.08	157.668	0.000000
Intercropping x P	107.76	6	17.96	4.182	0.001158
Intercropping x season	61.86	6	10.31	2.401	0.035927
P x season	116.08	4	29.02	6.758	0.000112
Intercropping x P x season	63.06	12	5.25	1.224	0.284250
Error	309.19	72	4.29		

Sweetpotato vine yield

Source	SS	DF	MS	F	P
Intercropping	73.05	3	24.35	3.317	0.024593
P	411.77	2	205.88	28.046	0.000000
Season	1065.62	2	532.81	72.581	0.000000
Intercropping x P	258.01	6	43.00	5.858	0.000051
Intercropping x season	203.21	6	33.87	4.614	0.000511
P x season	225.63	4	56.41	7.684	0.000033
Intercropping x P x season	193.30	12	16.11	2.194	0.020756
Error	528.55	72	7.34		

Sweetpotato number of storage roots plant^{-1}

Source	SS	DF	MS	F	P
Intercropping	12.860	3	4.287	3.017	0.035353
P	47.327	2	23.663	16.656	0.000001
Season	12.616	2	6.308	4.440	0.015198
Intercropping x P	39.076	6	6.513	4.584	0.000541
Intercropping x season	27.254	6	4.542	3.197	0.007717
P x season	10.931	4	2.733	1.923	0.115746
Intercropping x P x season	8.053	12	0.671	0.472	0.924570
Error	102.293	72	1.421		

Sweetpotato storage root diameter

Source	SS	DF	MS	F	P
Intercropping	13.048	3	4.349	4.262	0.007920
P	1.027	2	0.513	0.503	0.606776
Season	1.678	2	0.839	0.822	0.443490
Intercropping x P	13.701	6	2.283	2.237	0.049051
Intercropping x season	5.281	6	0.880	0.862	0.526749
P x season	2.015	4	0.504	0.494	0.740458
Intercropping x P x season	12.468	12	1.039	1.018	0.441983
Error	73.480	72	1.021		

Sweetpotato storage root length

Source	SS	DF	MS	F	P
Intercropping	8.47	3	2.82	0.740	0.531761
P	40.93	2	20.46	5.363	0.006743
Season	126.60	2	63.30	16.590	0.000001
Intercropping x P	27.75	6	4.62	1.212	0.310153
Intercropping x season	83.24	6	13.87	3.636	0.003305
P x season	94.42	4	23.61	6.187	0.000246
Intercropping x P x season	96.50	12	8.04	2.108	0.026731
Error	274.73	72	3.82		

Total biomass yield in sweetpotato

Source	SS	DF	MS	F	P
Intercropping	284.9	3	95.0	9.31	0.000028
P	1088.8	2	544.4	53.38	0.000000
Season	4967.6	2	2483.8	243.56	0.000000
Intercropping x P	337.4	6	56.2	5.51	0.000096
Intercropping x season	275.0	6	45.8	4.49	0.000641
P x season	469.1	4	117.3	11.50	0.000000
Intercropping x P x season	217.3	12	18.1	1.78	0.068720
Error	734.3	72	10.2		

Harvest index in sweetpotato

Source	SS	DF	MS	F	P
Intercropping	1655.9	3	552.0	27.228	0.000000
P	257.8	2	128.9	6.359	0.002862
Season	1204.3	2	602.2	29.704	0.000000
Intercropping x P	466.6	6	77.8	3.836	0.002248
Intercropping x season	497.7	6	83.0	4.092	0.001376
P x season	145.4	4	36.3	1.793	0.139701
Intercropping x P x season	501.5	12	41.8	2.061	0.030555
Error	1459.6	72	20.3		

Sweetpotato partial LER

Source	SS	DF	MS	F	P
Intercropping	4.0539	3	1.3513	35.217	0.000000
P	0.6229	2	0.3114	8.117	0.000663
Season	1.2324	2	0.6162	16.059	0.000002
Intercropping x P	0.7449	6	0.1242	3.236	0.007164
Intercropping x season	0.7482	6	0.1247	3.250	0.006969
P x season	0.3445	4	0.0861	2.245	0.072571
Intercropping x P x season	0.7734	12	0.0644	1.680	0.089485
Error	2.7627	72	0.0384		

Soybean partial LER

Source	SS	DF	MS	F	P
Intercropping	0.9197	3	0.3066	3.822	0.013389
P	5.5562	2	2.7781	34.634	0.000000
Season	1.4902	2	0.7451	9.289	0.000258
Intercropping x P	1.9305	6	0.3218	4.011	0.001606
Intercropping x season	0.8359	6	0.1393	1.737	0.124751
P x season	0.9645	4	0.2411	3.006	0.023680
Intercropping x P x season	1.0302	12	0.0859	1.070	0.397639
Error	5.7754	72	0.0802		

Groundnut partial LER

Source	SS	DF	MS	F	P
Intercropping	0.46693	3	0.15564	13.687	0.000000
P	0.04167	2	0.02083	1.832	0.167444
Season	0.02942	2	0.01471	1.294	0.280530
Intercropping x P	0.12795	6	0.02132	1.875	0.096798
Intercropping x season	0.03602	6	0.00600	0.528	0.785261
P x season	0.04340	4	0.01085	0.954	0.437994
Intercropping x P x season	0.27522	12	0.02294	2.017	0.034739
Error					

Groundnut pod yield

Source	SS	DF	MS	F	P
Intercropping	2.9442	3	0.9814	21.13	0.000000
P	9.9673	2	4.9837	107.30	0.000000
Season	0.6841	2	0.3421	7.36	0.001231
Intercropping x P	0.9677	6	0.1613	3.47	0.004532
Intercropping x season	0.1745	6	0.0291	0.63	0.708890
P x season	0.6019	4	0.1505	3.24	0.016776
Intercropping x P x season	1.4862	12	0.1238	2.67	0.005122
Error	3.3442	72	0.0464		

Shelled groundnut yield

Source	SS	DF	MS	F	P
Intercropping	1.9967	3	0.6656	8.226	0.000088
P	5.3139	2	2.6570	32.839	0.000000
Season	0.8474	2	0.4237	5.237	0.007528
Intercropping x P	1.3494	6	0.2249	2.780	0.017320
Intercropping x season	0.4081	6	0.0680	0.841	0.542661
P x season	0.0616	4	0.0154	0.190	0.942748
Intercropping x P x season	0.5285	12	0.0440	0.544	0.878208
Error	5.8253	72	0.0809		

Groundnut number of pods plant^{-1}

Source	SS	DF	MS	F	P
Intercropping	408.0	3	136.0	6.890	0.000383
P	1390.2	2	1328.5	67.299	0.000000
Season	2657.1	2	695.1	35.211	0.000000
Intercropping x P	106.1	6	27.6	1.398	0.227185
Intercropping x season	165.6	6	17.7	0.895	0.503078
P x season	502.9	4	125.7	6.369	0.000191
Intercropping x P x season	589.1	12	49.1	2.487	0.008755
Error	1421.3	72	19.7		

Soybean pod yield

Source	SS	DF	MS	F	P
Intercropping	6.567	3	2.189	3.387	0.022590
P	12.116	2	6.058	9.375	0.000241
Season	21.150	2	10.575	16.365	0.000001
Intercropping x P	17.123	6	2.854	4.416	0.000742
Intercropping x season	8.344	6	1.391	2.152	0.057676
P x season	1.805	4	0.451	0.698	0.595523
Intercropping x P x season	12.025	12	1.002	1.551	0.126358
Error	46.527	72	0.646		

Soybean 100-seed weight

Source	SS	DF	MS	F	P
Intercropping	57.2	3	19.1	1.32	0.273059
P	1338.6	2	669.3	46.51	0.000000
Season	590.3	2	295.2	20.51	0.000000
Intercropping x P	104.7	6	17.4	1.21	0.310107
Intercropping x season	92.8	6	15.5	1.07	0.385611
P x season	90.9	4	22.7	1.58	0.188924
Intercropping x P x season	492.5	12	41.0	2.85	0.002941
Error	1036.1	72	14.4		

Soybean number of pods plant^{-1}

Source	SS	DF	MS	F	P
Intercropping	1504	3	501	10.62	0.000007
P	5339	2	2670	56.56	0.000000
Season	3254	2	1627	34.46	0.000000
Intercropping x P	1628	6	271	5.75	0.000063
Intercropping x season	505	6	84	1.78	0.114430
P x season	263	4	66	1.39	0.245078
Intercropping x P x season	640	12	53	1.13	0.350693
Error	3399	72	47		

Appendix 4. ANOVA tables for chapter 6: Influence of intercropping orange-fleshed sweetpotato with groundnut and soybean at different P levels on the nutritional quality in sweetpotato storage roots.

Percent starch content in the sweetpotato storage roots

Source	SS	DF	MS	F	P
Intercropping	273.5	3	91.2	21.8	0.000000
P	731.1	2	365.5	87.4	0.000000
Season	1843.6	2	921.8	220.5	0.000000
Intercropping x P	39.9	6	6.6	1.6	0.162304
Intercropping x season	52.7	6	8.8	2.1	0.063564
P x season	133.3	4	33.3	8.0	0.000022
Intercropping x P x season	36.0	12	3.0	0.7	0.730077
Error	301.0	72	4.2		

Percent dry matter in the sweetpotato storage roots

Source	SS	DF	MS	F	P
Intercropping	31.08	3	10.36	86.8	0.000000
P	210.85	2	105.42	882.8	0.000000
Season	3.50	2	1.75	14.7	0.000005
Intercropping x P	3.77	6	0.63	5.3	0.000154
Intercropping x season	4.16	6	0.69	5.8	0.000056
P x season	2.73	4	0.68	5.7	0.000469
Intercropping x P x season	2.88	12	0.24	2.0	0.035277
Error					

Percent fructose sweetpotato storage roots

Source	SS	DF	MS	F	P
Intercropping	0.690	3	0.230	0.584	0.627408
P	0.996	2	0.498	1.264	0.288654
Season	41.733	2	20.867	52.975	0.000000
Intercropping x P	1.689	6	0.281	0.715	0.638954
Intercropping x season	0.682	6	0.114	0.288	0.940614
P x season	5.770	4	1.442	3.662	0.009017
Intercropping x P x season	4.198	12	0.350	0.888	0.562447
Error	28.361	72	0.394		

Percent glucose sweetpotato storage roots

Source	SS	DF	MS	F	P
Intercropping	2.473	3	0.824	3.31	0.024807
P	0.480	2	0.240	0.96	0.386564
Season	35.894	2	17.947	72.05	0.000000
Intercropping x P	2.731	6	0.455	1.83	0.105736
Intercropping x season	11.098	6	1.850	7.43	0.000003
P x season	8.536	4	2.134	8.57	0.000010
Intercropping x P x season	6.099	12	0.508	2.04	0.032464
Error	17.935	72	0.249		

Percent sucrose in sweetpotato storage roots

Source	SS	DF	MS	F	P
Intercropping	80.56	3	26.85	5.198	0.002631
P	85.53	2	42.77	8.278	0.000581
Season	53.02	2	26.51	5.132	0.008250
Intercropping x P	29.60	6	4.93	0.955	0.461788
Intercropping x season	79.53	6	13.25	2.566	0.026178
P x season	26.77	4	6.69	1.296	0.279913
Intercropping x P x season	120.66	12	10.05	1.946	0.042531
Error	371.97	72	5.17		

B carotene content in sweetpotato storage roots

Source	SS	DF	MS	F	P
Intercropping	13.36	3	4.45	0.649	0.586250
P	19.08	2	9.54	1.390	0.255730
Season	530.69	2	265.34	38.664	0.000000
Intercropping x P	25.61	6	4.27	0.622	0.712166
Intercropping x season	37.42	6	6.24	0.909	0.493610
P x season	137.97	4	34.49	5.026	0.001251
Intercropping x P x season	87.66	12	7.31	1.064	0.402449
Error	494.13	72	6.86		

Fe content in sweetpotato storage roots

Source	SS	DF	MS	F	P
Intercropping	0.1580	3	0.0527	1.94	0.130416
P	0.1465	2	0.0733	2.70	0.073952
Season	0.1327	2	0.0664	2.45	0.093726
Intercropping x P	0.8417	6	0.1403	5.17	0.000180
Intercropping x seasons	0.7544	6	0.1257	4.64	0.000490
P x season	0.3044	4	0.0761	2.81	0.031818
Intercropping x P x season	0.2770	12	0.0231	0.85	0.598570
Error	1.9527	72	0.0271		

B carotene yield (kg ha^{-1}) from sweetpotato production

	SS	DF	MS	F	P
Intercropping	3.1157	3	1.0386	27.470	0.000000
P	2.6563	2	1.3282	35.130	0.000000
Season	13.9492	2	6.9746	184.477	0.000000
Intercropping x P	0.7350	6	0.1225	3.240	0.007101
Iintercropping x S	0.6718	6	0.1120	2.962	0.012182
P x Season	0.8387	4	0.2097	5.546	0.000599
Interceppingx P x season	0.8061	12	0.0672	1.777	0.068518
Error	2.7221	72	0.0378		

Fe yield (kg ha^{-1}) from sweetpotato production

	SS	DF	MS	F	P
Intercropping	0.018067	3	0.006022	31.811	0.000000
P	0.008082	2	0.004041	21.346	0.000000
Season	0.044583	2	0.022292	117.751	0.000000
Intercropping x P	0.001726	6	0.000288	1.519	0.184148
Iintercropping x S	0.006117	6	0.001020	5.385	0.000122
P x Season	0.002864	4	0.000716	3.782	0.007566
Interceppingx P x season	0.001453	12	0.000121	0.640	0.801590
Error	0.013630	72	0.000189		

Zn yield from sweetpotato (kg ha^{-1})

	SS	DF	MS	F	P
Intercropping	0.008775	3	0.002925	30.898	0.000000
P	0.005271	2	0.002635	27.837	0.000000
Season	0.035611	2	0.017805	188.075	0.000000
Intercropping x P	0.001492	6	0.000249	2.626	0.023308
Iintercropping x S	0.001217	6	0.000203	2.143	0.058723
P x Season	0.001945	4	0.000486	5.136	0.001070
Interceppingx P x season	0.001233	12	0.000103	1.085	0.385226
Error	0.006816	72	0.000095		

Table of Total and Olsen P results

Appendix 5. Effect of intercropping sweetpotato, groundnut and soybean at varying P levels on total and Olsen P at Umbeluzi research station in the 2013/14/ 2014/15 and 2015/16 growing seasons.

P level	Intercrops	Total P (mg kg^{-1})			Olsen P (mg 100g^{-1})		
		2013	2014	2015	2013	2014	2015
0	Sole groundnut	429.0^{dbe}	258.9^{msl}	422.1^{dbe}	3.2^{cdb}	1.4^{iog}	1.2^{oi}
	Sole soybean	389.1^{decefghijk}	227.4^{sn}	378.7^{mhnopqr}	3.8^{cb}	0.9^{mo}	1.6^{ifjklmn}
	Sole sweetpotato	432.1^{db}	223.5^{so}	319.1^{mgno}	3.3^{cd}	0.9^{oi}	0.2^{o}
	Soybean-groundnut	413.1^{dbefg}	216.5^{sq}	423.1^{dbe}	5.3^{a}	1.3^{ioh}	2.2^{idjkl}
	Sweetpotato-groundnut	409.1^{dcefgh}	296.7^{msl}	397.2^{msi}	3.1^{cbd}	0.7^{no}	1.4^{iog}
	Sweetpotato-soybean	363.7^{dcefghijk}	232.2^{sn}	382.5^{dcefgh}	3.0^{cbd}	0.9^{om}	1.7^{iejklmn}
	Sweetpotato-soybean-groundnut	377.9^{dcefghijk}	243.4^{msl}	421.1^{dbef}	3.0^{cbd}	0.8^{om}	2.3^{idjk}
	Mean	**2814**	**1699**	**2744**	**24.7**	**6.9**	**10.6**
20	Sole groundnut	376.8^{dcefghijk}	251.1^{msl}	427.5^{dbe}	2.2^{idjk}	2.3^{idjk}	1.5^{ifjklmn}
	Sole soybean	451.4^{abc}	213.4^{sr}	282.1^{msk}	2.7^{cdef}	1.5 ^{ifjklmn}	1.6 ^{ifjklmn}
	Sole sweetpotato	420.1^{dbef}	218.5^{sp}	311.5^{mfn}	2.7 ^{cdef}	1.6 ^{ifjklmn}	0.8^{om}
	Soybean-groundnut	343.3^{dcefghijk}	275.8^{ms}	382.0^{dcefghij}	2.1^{idjklm}	2.9^{cbde}	1.7 ^{ifjklmn}
	Sweetpotato-groundnut	397.2^{dcefgh}	225.8^{msl}	331.8^{me}	3.1^{cbd}	1.2^{io}	1.1^{oig}
	Sweetpotato-soybean	389.1^{dcefgh}	230.6^{sn}	375.4^{dne}	2.5^{cdefg}	1.0^{ok}	1.3^{ion}
	Sweetpotato-soybean-groundnut	399.1^{dcefgh}	247.4^{ms}	359.2^{dcefghijk}	2.7 ^{cdef}	1.2^{oi}	1.4^{iog}
Mean		**2777**	**1663**	**2470**	**18**	**11.7**	**9.4**
40	Sole groundnut	380.4^{dcefghijk}	238.3^{ms}	315.0^{dcefghijk}	3.0^{idb}	0.7^{no}	1.5 ^{ifjklmn}
	Sole soybean	369.1^{dcefghi}	209.5^{s}	443.6^{abc}	2.7 ^{cdef}	1.1^{bj}	2.4^{id}
	Sole sweetpotato	507.7^{ab}	231.3^{sn}	323.7^{dcefghijk}	4.1^{ab}	0.7^{no}	0.5^{om}
	Soybean-groundnut	360.1 ^{defghijkl}	234.7^{msl}	345.0 ^{defghijkl}	2.4 ^{idj}	2.3^{idjk}	1.5 ^{ifjklmn}
	Sweetpotato-groundnut	314.9^{mgnopq}	252.9^{sp}	402.3^{dcefgh}	2.6^{cdefgh}	2.7 ^{cdef}	1.4^{io}
	Sweetpotato-soybean	387.8^{dcefghi}	227.6^{ns}	332.1^{dcefghijk}	2.6 ^{cdefgh}	0.8^{om}	1.5 ^{ifjklmn}
	Sweetpotato-soybean-groundnut	536.9^{a}	227.8^{ns}	378.4^{dcefghijk}	2.1^{cdef}	0.6^{on}	1.3^{ioh}
Mean		**2857**	**1622**	**2540**	**19.5**	**8.9**	**10.1**
% CV		18.4			41.8		
$LSD_{0.05}$		99.2			1.3		