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EFFECT OF MAIZE INTERCROP PLANT DENSITIES ON YIELD AND β-CAROTENE CONTENTS OF ORANGE-FLESHED SWEETPOTATOES

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ABSTRACT

Despite efforts to demonstrate the value of orange-fleshed sweetpotato (OFSP) (*Ipomoea batatas* L.) and quality protein maize (*Zea mays* L.) in combating vitamin A and protein malnutrition, small land holdings by rural poor farmers still limit the crops' overall production in Africa. As such, intercropping and optimum plant density in cropping systems will help farmers to improve productivity of the crop, and hence, improve household food and nutrition security. This study determined the effect of maize plant population, in a sweetpotato-maize intercrop, on yields and β-carotene content of two popular OFSP cultivars, Ejumula and NASPOT 9 O (Kabode). Each variety was intercropped with maize variety Longe 5, at three plant densities (i.e. 41,666**,** 55,555 and 88,888 plants ha^{-1}), at Ngetta Zonal Agricultural Research and Development Institute in Uganda. While 55,555 plants of each OFSP cultivar were used for both sole and intercrops, the sole maize plot was 44,444 plants ha^{-1}. Maize and sweetpotato were harvested at 120 and 135 days after planting, respectively. β-carotene content and yield in sweetpotato roots were significantly ($P<0.05$) reduced by high maize density. Irrespective of maize density, NASPOT 9 O produced more root yields than Ejumula. Land Equivalent Ratios of >1.2 were obtained at maize intercrop densities of 41,666 and 55,555 plants ha^{-1}.

Key Words: *Ipomoea batatas*, land equivalent ratio, *Zea mays*

RÉSUMÉ

Malgré les efforts visant à démontrer la valeur nutritionnelle en combinaison de la patate douce à chaire orange (OFSP) (*Ipomoea batatas* L.) et du maïs à grande valeur proteique (*Zea mays* L.) dans la lutte contre la malnutrition liée au manque de la vitamine A et de proteine, les petits producteurs Africains continuent de limiter les rendements de leur cultures. A cet effet, l'association des cultures doublée d'une densité optimale des plants dans les systems de cultures, aiderait les producteurs à améliorer les rendements de leurs cultures et par consequent améliorer la qualité de vie dans les ménages et assurer la sécurité alimentaire. La présente étude a détérminé l'effet de la densité des plants de maïs, dans une culture associée avec la patate douce sur le rendements et la teneur en b-carotene de deux variétés populaires de patate douce OFSP, Ejumula et NASPOT 9 O (Kabode). Chaque variété a été plantée en association avec la variété de maïs Longe 5, à trois différentes densités (i.e. 41,666, 55,555 et 88,888 plants ha^{-1}), et ceci à l'Institut Zonale de Developpement et de Recherche en Agriculture de Ngetta en Ouganda. Pendant que la densité 55,555 plants de chaque variété de OFSP a été utilisé dans la culture solitaire et en association, la culture solitaire de maïs était à 44,444 plants ha^{-1}. Maïs et patate douce ont été récoltés respectivement à 120 et 135 jours après. La teneur en β-carotene et le rendement en tubercules de patate douce ont été réduits de façon significative (P<0.05) par une densité forte de maïs. Quelle que soit la densité de maïs, NASPOT 9 O a produit plus de tubercules qu'Ejumula. Le ratio équivalent était >1.2 pour une densité de maïs de 41,666 et 55,555 plants ha^{-1}, en culture d'association.

Mots Clés: Ipomoea batatas, ratio équivalent, *Zea mays*

INTRODUCTION

Sweetpotato (*Ipomoea batatas* L.) ranks third among the staple crops in Eastern and Central Africa sub-region (CIP, 2015). It is a preferred disaster mitigation crop because it is hardy, easy to grow and matures in a short time (Odongo *et al*., 2007). Traditionally, sweetpotato production in Uganda and neighbouring countries, has been based on white-fleshed varieties, which have low or no β-carotene (Low *et al*., 2001). However, orange-fleshed sweetpotato (OFSP) varieties, rich in β-carotene, a precursor to vitamin A, have been identified and demonstrated to combat vitamin A deficiency (VAD) (Van Jaarsveld *et al*., 2005; Low *et al*., 2007); and are being strongly promoted in Eastern Africa (Tumwegamire *et al*., 2004). Vitamin A deficiency is prevalent in Uganda, with 38% of children and 36% women reportedly affected (UBOS and ICF International Inc., 2012). Severe VAD causes blindness, premature death, lowers disease resistance in children and reduces survival of mothers during childbirth (Frossard *et al*., 2000).

Maize (*Zea mays* L.) is also one of the major staple food crops in countries like Uganda, ranking fourth after plantain, cassava and sweetpotato (FAO, 2010). Conventional white maize is unfortunately deficient in protein because of the limiting quantities of essential amino acids: lysine and tryptophan (Vasal, 2001). As such, the large percentage of the population in developing countries who depend on maize, are exposed to protein or essential amino acid deficiencies and associated ailments (Krivanek *et al*., 2007). Quality protein maize (QPM) has twice the amount of limiting amino acids- lysine and tryptophan contents compared to conventional maize (Krivanek *et al*., 2007), and is thus being promoted to combat protein malnutrition in humans.

Bio-fortified crops like QPM and OFSP were introduced in Uganda, but one of the challenges to their wide adoption is shortage of land due to the increasing human population (UBOS, 2007), which impedes expansion of other crop varieties as well. In such situations, intensive cropping practices such as intercropping are recommended (Lithourgidis *et al*., 2011).

Traditionally, sweetpotato has been grown as an intercrop with beans, cassava, maize and pigeon pea (Bashaasha *et al*., 1995; Gibson, 2006). Yields of crops in intercrops have been reported to fluctuate with component crop populations (Egbe and Idoko, 2009; Ossom *et al*., 2009; Ossom, 2010). A maize-sweetpotato intercrop with 50% of the recommended maize plant population, gave the highest yield, while the other mixtures with more or less maize gave less maize yields (Oswald *et al*., 1996). However, sweetpotato root yield was reduced.

A different intercrop study reported that sweetpotato yield was reduced by up to 56%, while maize yields were not affected (Webi, 2007).

In Uganda, yield responses of either OFSP or QPM under intercropping are not known. Research on sweetpotato elsewhere indicated a cultivar- and location-dependent response to intercropping (Oswald *et al*., 1996). In a study by Oswald *et al*. (1995a), shade induced by a mesh affected sweetpotato root yield, although the effects were variety dependent. Further, the effect of intercropping on β-carotene content and yield in OFSP is not known.

This study was, therefore, designed to investigate the productivity of OFSP varieties and QPM in intercrop at varying plant densities of the latter and to determine the effect of intercropping on β-carotene content and yield of OFSP.

MATERIALS AND METHODS

A study was conducted at Ngetta Zonal Agricultural Research and Development Institute (Ngetta ZARDI) in northern Uganda, during the first (April-June) and second (July-October) rains of 2011. Ngetta ZARDI is found at an altitude of 1091 m, latitude 2° 17' N and longitude 32° 56' E. It has a temperature range of 22.5 to 29 °C and bimodal rains, amounting to 1200 to 1600 mm per *annum*. The soils are sandy clay loam, classified as Ferralsols.

Two OFSP varieties, Ejumula and NASPOT 9 O, and one quality protein maize variety (Longe 5) were used in the study. On plots measuring 4.5 m long by 4.8 m wide, each OFSP variety was planted on four ridges each measuring 4.5 m long and 1.2 m wide. On each ridge, two rows of vines were planted at a spacing of 0.3 m by 0.3 m, giving 55,555 plants per ha. Maize was intercropped with each of the sweetpotato varieties, except in the sole sweetpotato and maize check plots. Maize in the intercrops was planted in furrows between the ridges, at three different plant densities. Plant density 1, where one row of maize, was planted with one seed per hill at 0.25 m inter-row spacing, giving 41,666 plants ha^{-1}; plant density 2 where one row of maize was planted with two seeds per hill at 0.375 m intra-row spacing giving 55,555 plants ha^{-1}; and plant density 3 where two rows of maize, 0.3 m apart, were planted using two seeds per hill at 0.375 m intra-row spacing, giving 88,888 plants ha^{-1}.

The three maize intercrop populations with sweetpotato varieties were laid out following a modification of a design by Webi (2007). The sole maize check plots were planted in rows at spacings of 0.75 m by 0.3 m, giving rise to 44,444 plants ha^{-1}. A randomised complete block design (RCBD), with four replications, was used.

One month after planting, a blanket fertiliser was applied to all plots to invigorate plants, especially for maize. In the first season, N: P: K (17:17:17) fertiliser was applied at a rate of 50 kg ha^{-1}; while in the second season, N, P and K were applied singly as urea, triple superphosphate and muriate of potash at rates of 50, 50 and 60 kg ha^{-1} for N, P_2O_5 and K_2O, respectively. The method in the second year enabled application of specific rates of the individual elements following recommendations from Makerere University, after analysing soil samples from the site. The plots were kept weed free through regular manual weeding.

A net plot measuring 2.4 m x 4.2 m [determined by excluding the two outer ridges (2.4 m) and one extreme plant on either side of the inner ridges] was used to collect data at harvest. At 86 days after planting (DAP), the sweetpotato canopy had fully developed and leaf area index (LAI) was determined in all plots using the LAI-2200 Plant Canopy Analyser, from randomly chosen positions within each plot; while facing in the same direction as described in the operating manual (LI COR, 2010). Using the optical sensor, two readings above and four below the canopy (as recommended) were taken in each plot. The sensor was covered with a 90° opaque view cap to restrict the operator and untargeted area from the lens view (LI COR, 2010).

Readings were taken between 3:30-5:30 pm under a clear sky. At 120 DAP, maize was harvested and data on grain yield collected after drying. At 135 DAP, sweetpotato was also harvested by uprooting all the plants in the net plot and number of plants harvested recorded. Roots and vines weights from each plot were also recorded. A sample of five roots with no physical damage, weighing 100 to 300 g, was taken for dry matter and β-carotene 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 °C for 72 hours. Dry samples were weighed, milled into flour in a stainless steel mill, and stored in Kraft paper bags. Percent root dry matter was determined as a ratio of dry to fresh weights.

β-carotene 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 (NIRSystems, 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 Felde *et al.*, 2009). The reference method for NIRS calibration was high performance liquid chromatography (HPLC) according to Rodriguez-Amaya and Kimura (2004) for β-carotene. Values of β-carotene content in the roots were used to determine β-carotene yield (metric tonnes per hectare) as follows:

$$Y = \frac{t}{s} \times d \quad \text{...} \quad (1)$$

Where:

Y= β-carotene yield in t ha^{-1};
t = β-carotene content in roots of the corresponding sole or intercrop treatments in t ha^{-1};
s = dry weight of the test samples (t ha^{-1}) equal to 0.0001 for all treatment root samples; and
d = dry weight of total root yield (t ha^{-1}).

Biomass was obtained as fresh weights of vines and roots per unit area. The Harvest Index was calculated to ascertain the main organs of assimilate allocation in the sweetpotato plant in all treatments.

Data were subjected to Analysis of Variance (ANOVA) using SAS Version 9.0. Percentage data were arc-sine transformed to stabilise variances. Treatment means were separated using Least Significant Difference (LSD) at $\alpha<0.05$. The land use efficiency was assessed using the Land Equivalent Ratio (LER) according to Mead and Willey (1980).

RESULTS

Leaf Area Index (LAI). LAI results are shown in Table 1. Seasonal differences, cropping systems and genotypes were all significant ($P<0.05$) for LAI. Overall, LAI was higher in season two (3.80) than in season one (2.66). LAI means for SP-Maize density 1 and sole sweetpotato were significantly lower than sweetpotato-maize densities 2 and 3. Irrespective of the cropping system and season, Ejumula had higher LAI means than NASPOT 9 O.

Yield and harvest index (HI). Results for sweetpotato root and biomass yields, and harvest index (HI) are shown in Table 1. Seasonal effects were significant for root yield and HI, but not for biomass yield. Differences in cropping systems were, however, significant for root yield and biomass yield, but not for HI. For both root yield and biomass yield, a clear decreasing trend was observed across the cropping systems, being highest for sole sweetpotato crop (i.e., 12.2 t ha^{-1} for root yield and 42.0 t ha^{-1} for biomass yield); and lowest for SP-Maize density 3 (i.e., 4.5 t ha^{-1} for root yield and 19.0 t ha^{-1} for biomass yield). Reductions in root and biomass yields revealed a better picture of the declining trend in the two parameters, as a result of increasing maize plant densities in the sweetpotato intercrops. For example, sweetpotato root yield reductions of 36.7, 40 and 62.5% were obtained at SP-maize densities 1, 2 and 3, respectively. For biomass yields, reductions of 32.6, 32.1 and 54.8% occurred at SP-maize densities 1, 2 and 3, respectively.

The HI of sweetpotato across cropping systems did not vary significantly. Thus, the proportion of roots in reference to total biomass was not significantly affected by the cropping systems. Sweetpotato genotype differerences were significant for root yield and HI, but not for biomass yield. NASPOT 9 O had higher root yields and HI than Ejumula.

Dry matter, β-carotene content and yield. The results for sweetpotato root dry matter content, β-carotene content and β-carotene yield are shown in Table 2. Season effects were not significant for β-carotene content, but significant for dry matter and β-carotene yield. A significant difference in dry matter was observed across the SP-Maize intercrop densities with SP-Maize density 3 having the highest dry matter content (33.0%) and sole sweetpotato the lowest (32.2%). β-carotene content varied significantly across cropping systems, being highest in the sole sweetpotato (24.2 mg 100 g^{-1}) and lowest in SP-Maize density 3 (20.3 mg 100 g^{-1}). There were higher β-carotene yields in season 2 than season

TABLE 1. The effect of season, cropping system and varieties on growth and yields of orange-fleshed sweetpotato in northern Uganda

Factors of variation	LAI	Root yield (t ha^{-1})	Biomass yield (t ha^{-1})	HI (%)
(a) Seasons				
Season 1	2.66	6.4	28.0	24.0
Season 2	3.80	9.4	30.9	29.2
Mean	3.23	7.9	29.4	26.6
LSD (0.05)	0.20	1.5	NS	4.8
CV (%)	12.50	37.0	26.1	35.9
(b) Cropping system				
SP sole	3.02	12.2	42.0	28.8
SP-Maize density 1	3.06	7.6	28.3	26.4
SP-Maize density 2	3.47	7.2	28.5	26.3
SP-Maize density 3	3.36	4.5	19.0	24.9
Mean	3.23	7.9	29.4	26.6
LSD (0.05)	0.29	2.1	5.5	NS
CV (%)	12.50	37.0	26.1	35.9
(c) SP genotypes				
Ejumula	3.54	5.1	30.2	16.8
NASPOT 9 O	2.92	10.6	28.7	36.4
Mean	3.23	7.9	29.4	26.6
LSD (0.05)	0.20	1.5	NS	4.8
CV (%)	12.50	37.0	26.1	35.9

NS = not significant at $P<0.05$

1. β-carotene yields varied significantly across cropping systems, being higher in the sole sweetpotato crops than any of the SP-maize densities, but showed a declining trend with increasing maize plant density in the intercrop.

Genotypes were significantly different for root dry matter, β-carotene content and β-carotene yield. Ejumula had higher dry matter content (33.5%) and β-carotene content (23.2 mg 100 g^{-1}) than NASPOT 9 O (31.5% and 21.1 mg 100 g^{-1}, respectively). However, NASPOT 9 O had higher β-carotene yields than Ejumula because of the higher root yield per area.

Grain yield. Maize grain yield obtained for different treatments and seasons are shown in Table 3. Unlike sweetpotato root yields, there were no significant season effects on maize grain yield. Instead maize grain yield varied across the different maize plant densities, being significantly higher for the sole maize crop (5.4 t ha^{-1}) than each of the other intercrop treatments. The grain yield means for SP- maize density 1 (3.4 t ha^{-1}), 2 (3.8 t ha^{-1}), and 3 (4.0 t ha^{-1}) were not significantly different.

Land use efficiency by the intercrops. The partial LERs were generally higher in maize than in sweetpotato (Table 4). Sweetpotato partial LER in density 3 (0.37) was considerably low, denoting a substantial yield reduction of sweetpotato in density 3. The LERs in all the cropping systems, however, were greater than 1.

DISCUSSION

The higher LAIs during season 2 (Table 1) are probably due to more favourable weather

TABLE 2. The effect of season, cropping system and varieties on dry matter, β-carotene content and yield in orange-fleshed sweetpotato in northern Uganda

Factors of variation	Dry matter (%)	β-carotene content (mg 100 g^{-1})	β-carotene yield(t ha^{-1})
(a) Seasons			
Season 1	33.6	22.2	4.2 x10^{-4}
Season 2	31.4	22.1	5.6 x10^{-4}
Mean	32.5	22.2	4.9 x10^{-4}
LSD (0.05)	0.5	NS	1 x10^{-4}
CV%	3.0	17.2	43.9
(b) Cropping system			
SP sole	32.2	24.2	8.1x10^{-4}
SP-Maize density 1	32.4	22.7	4.7 x10^{-4}
SP-Maize density 2	32.5	21.4	4.3 x10^{-4}
SP-Maize density 3	33.0	20.3	2.7 x10^{-4}
Mean	32.5	22.2	4.9 x10^{-4}
LSD (0.05)	0.7	2.7	2.0 x10^{-4}
CV%	3.0	17.2	43.9
(c) SP genotypes			
Ejumula	33.5	23.2	3.8 x10^{-4}
NASPOT 9 O	31.5	21.1	6.1 x10^{-4}
Mean	32.5	22.2	4.9 x10^{-4}
LSD (0.05)	0.5	1.9	1.0 x10^{-4}
CV%	3.0	17.2	43.9

TABLE 3. Maize grain yield across different sweetpotato (SP) - maize intercropping systems in northern Uganda

Factor of variation	Grain yield (t ha^{-1})
(a) Seasons	
Season 1	4.0
Season 2	4.3
Mean	4.1
LSD (0.05)	NS
CV (%)	25.0
(b) Cropping system	
SP-Maize density 1	3.4
SP-Maize density 2	3.8
SP-Maize density 3	4.0
Maize sole	5.4
Mean	4.1
LSD (0.05)	0.7
CV (%)	25.0

TABLE 4. The Land Equivalent Ratio (LER) of sweetpotato intercropped with maize in the three plant densities in northern Uganda

Cropping system	Sweetpotato	Maize	LER
SP-Maize density 1	0.62	0.63	1.24
SP-Maize density 2	0.59	0.70	1.23
SP-Maize density 3	0.37	0.73	1.1

conditions (data not presented). Situations of limited moisture have been reported (Xoconostle-Cázares *et al*., 2011, Hajibabaee *et al*., 2012) to impair plant growth and cause plants to reduce their foliar area to lessen water loss. Also, leaf growth was found to be severely inhibited at the onset of drought (Chaves *et al*., 2003), and more severe effects were observed in maize which is more sensitive to harsh weather conditions (Aslam *et al*., 2013).

The increasing trends of LAI from the sole sweetpotato crop to increasing maize plant densities in the intercrop treatments is possibly due to the increasing number of maize plants. Similarly, Jamshidi *et al.* (2008) reported increases in the LAI with increasing maize density in a maize potato intercrop in Iran. The higher LAI values were a result of the collective sum of leaf coverage of the two crops (sweetpotato and maize). The higher LAI observed in Ejumula-maize intercrops than NASPOT 9 O-maize intercrops, confirms that Ejumula is genetically more vegetative than NASPOT 9 O, an observation previously made by Mwanga *et al*., 2007; 2009) and Tumwegamire *et al.* (2014).

Like LAI, the higher root yields and HI in season 2 (Table 1) are again probably due to favorable weather conditions experienced in season two than in season one. Villareal and Hsu (1982), and Byamukama *et al.* (2007) reported variation in sweetpotato root yields across seasons and attributed it to seasonal weather variations. The decline in root and biomass yields observed in the present study, with the increasing maize plant populations, is in agreement with previous studies on sweetpotato (Egbe and Idoko, 2009; Ossom, 2010) and potatoes (Ebwongu *et al*, 2001). While studying sweetpotato-pigeonpea intercropping, Egbe and Idoko (2009) observed declining fresh root yield across five sweetpotato varieties. The decline was attributed to reduced photosynthesis by sweetpotato leaves, due to reduced solar radiation interception by shading from the taller pigeonpea plants. Similarly, in the potato-maize mixture, increase in maize plant population resulted in a decline in tuber yield (Ebwongu *et al*., 2001), due to reduced light interception by the potato hence the reduced photosynthetic activities of the crop. Apart from light, crops grown in association compete for water and nutrients in the soil (Oroka and Omoregie, 2007), and high plant densities result in increased competition for these resources, consequently causing low yields (Zamir *et al*., 2011).

Under induced shade conditions, Sale (1976) and Oswald *et al.* (1995a), respectively, studied potato and sweetpotato and all reported decreased numbers and bulking rate of potato tubers and sweetpotato roots, and hence, subsequent yield reductions. In potato, shade was reported to reduce potato cell proliferation and cell volume, resulting in a decline in fresh weight. This is because cell proliferation is positively correlated to plant photosynthetic status (Chen and Setter, 2003). On the other hand, shade on sweetpotato in the last stages of growth, has a more negative effect on root yield, than during the early stages of development (Oswald *et al*., 1995b). Thus, sweetpotato can best tolerate other crops up to the third month, beyond which root yields will decline severely.

Lack of variation in HI across cropping systems (Table 1) denotes the potential of sweetpotato to maintain a balance between the shoot and root biomasses in varying intercrop densities. Heuvel *et al.* (2004) noted that the root:shoot ratio decreases with increasing shade, and Valenzuela *et al.* (1991) reported that increased shading in cocoyam resulted in an increase in plant top:corm ratio a situation that did not manifest in our study.

The two study sweetpotato varieties exhibited marked differences for root yield (Table 1), but were similar for total biomass yield. NASPOT 9 O showed higher root yield potentials than Ejumula, a result previously reported by Mwanga *et al.* (2007; 2009) for several sites. Inherent differences in yielding potentials and yield stability, known to exist between varieties (Kapinga *et al*., 2010), can explain the consistent and significant differences in root yields observed between NASPOT 9 O and Ejumula in our study, even across the intercrop populations of maize. Variations in root yield potentials between varieties may arise due to differences in assimilate partitioning, which mainly depends on the sink strength, which in turn depends on sink size and sink activity/intensity (Marcelis, 1996; Yang *et al*., 2003). The roots as a sink seem to have been weak in attracting assimilates in Ejumula than in NASPOT 9 O, contributing a greater percentage of low root yields in the former. Differences in HI, observed across varieties in our study, are in agreement with previous studies (Bhagsari and Ashley, 1990).

The higher HI in NASPOT 9 O compared to Ejumula is associated with the high root yielding potential of the former than the latter (Tumwegamire *et al*., 2014). As noted earlier, Ejumula has more vegetation, which probably disadvantages its root yield potential. As observed by Lemaga (1992), when a plant has many leaves, not all are able to effectively photosynthesize due to such factors as internal shading, hence, some of the leaves become sinks rather than source organs.

The genetic differences between varieties could bear varied implications in the final usage and the seed systems of the two varieties. For example, Ejumula could be recommended in farming systems that, on top of producing roots for food, demand foliage for livestock feeding. For the same reasons, Ejumula can be a useful parent in a breeding programme to develop dual purpose varieties for farming systems that demand both roots and foliage. Additionally, more seed vines can be obtained per unit area from Ejumula than NASPOT 9 O in a vine multiplication system.

Significant increases in dry matter content across the sweetpotato-maize intercrop densities (Table 2), were observed, implying that intercropping and increasing maize plant densities increases root dry matter content of sweetpotato. Root dry matter content was lowest (32.2%) in sole sweetpotato and highest (33%) in SP-Maize density 3. This finding, contradicts a previous study by Ebwongu *et al.* (2001), where reduction in potato tuber dry matter content due to intercropping was reported. Also, Ennin *et al.* (2002) reported decreasing dry matter of soybean (*Glycine max* Merril) and maize plants with excess moisture availability. The explanation for the divergence of our study from previous ones is not clear and merits further investigation.

β-carotene levels did not vary significantly between seasons, but between sweetpotato-maize intercrop densities, with a decreasing trend (Table 2). The lower β-carotene contents observed at the highest maize plant density in the intercrop, are probably due to shading effect on sweetpotato crop by maize plants. Carotenoid compositions have previously been reported to decrease in leaves of yam (*Dioscorea zingiberensis*) at low light intensities (Li *et al*., 2002). Grumbach and Lichtenthaler (1982) reported that carotenoid biosynthesis was increased by light, while Simkin *et al.* (2003), found that in prolonged dark conditions, carotenoid biosynthesis is completely cut off in pepper (*Capsicum annuum)* leaves.

Apart from light or shade, some studies have reported the effect of varying environmental factors on the β-carotene levels in the sweetpotato roots (Andrade *et al*., 2009); while others (Gruneberg *et al*., 2005; Tumwegamire *et al*., 2011) reported very low effects on β-carotene content in sweetpotato by environmental factors. Gruneberg *et al*. (2009) explained that environment factors have low influences on majority of quality traits in crops. To validate our findings, the effect of shading on the levels of β-carotene in sweetpotato under controlled conditions merits further investigation.

β-carotene yields followed the same declining trends as observed for the root yields across increasing maize intercrop plant densities (Table 2). Moreover, β-carotene yield values were calculated using dry root yield and β-carotene content values. β-carotene in foods is an important precursor for vitamin A in the human body, and the observed decline trends imply negatively on the consumers nutrition security.

In this study, maize grain yield did not vary with seasons, but showed declining trends under intercropping systems with sweetpotato (Table 3). Previous studies have similarly reported reduction in maize grain yields from intercropping systems with soybean and climbing beans (Ennin *et al*., 2002; Niringiye *et al*., 2005).

From this study, increasing maize plant densities in intercrops seem to compensate for yield reductions, due to intercropping compared to the sole crop. For example, at sweetpotato-maize density 3, grain yield was only 25.9% less than that of sole crop, improving from 37% yield decline at sweetpotato-maize density 1. It is likely that the compensation effect has a limit after which it starts to decline. Sarlak *et al*. (2008) reported that increasing maize plant density beyond the optimum causes yield decline; while lower plant densities exhibit higher yields. Optimum maize plant density for maximum economic grain yield varies from 30,000 to over 90,000 plants ha^{-1} depending on water availability, soil fertility, maturity time, planting date and spacing (Olson and Sanders, 1988). This implies that increasing the maize population to 88,888 plants ha^{-1} (i.e., plant density 3) was not necessary since it caused no grain yield gain. Moreover, at sweetpotato-maize density 3, the root yields were reduced by 63%, hence, a lower maize population (55,555 plants ha^{-1}) that allows a higher sweetpotato yield in the intercrop would be most preferred.

Land Equivalent Ratios above 1 were obtained for all the intercrop systems (Table 4), indicating that intercropping was more efficient than sole cropping. Previous studies also showed yield advantages in maize/sweetpotato intercrops (Oswald *et al.*, 1996; Ossom *et al.*, 2009). Nevertheless, density 3 which had the highest maize population, had the lowest LER (1.1), indicating a negative interaction between sweetpotato and maize. This could have been mainly due to competition suffered by sweetpotato, which is a shorter crop than maize, resulting into the least partial LER at density 3; while that of maize increased. Muoneke and Mbah (2007) obtained similar results in cassava-okra intercrop, where the combination with the highest okra population had the least LER for cassava. Considering intercrop densities 1 and 2, the area planted to sole crops would need to be greater than the area under intercrops by 24 and 23%, respectively, for the two crops to produce the same combined yields as the yields from the intercrops. This clearly illustrates that intercrop densities 1 and 2 performed better than the sole crops and intercrop density 3, and are thus suitable levels for sweetpotato-maize intercropping systems.

The higher partial LERs for maize compared with sweetpotato, in all intercrop densities, suggest that sweetpotato/maize intercropping caused a higher yield reduction in sweetpotato than in maize, probably due to higher competitive ability of maize than sweetpotato. Maize, a C_4 and taller crop, in the mixture stood the advantage of fully capturing and utilising sunlight; while sweetpotato which is a C_3 plant and less efficient in carbon assimilation; was shaded by maize, hence, affecting its effective photosynthetic rates, which in turn was manifested in low root bulking rates. C_4 plants have an advantage for carbon fixation at high light intensities because of the high light saturation point (Skillman, 2008).

The results imply that at higher maize population in the intercrop, sweetpotato is out-competed for light, with the resultant significant root yield reductions. In a maize-bean intercropping experiment, Tsubo *et al.* (2004) did not observe reduction in maize yields, and maize was a more aggressive crop in the mixture. Also, Oswald *et al.* (1996) reported that the partial LER of maize in a sweetpotato-maize intercrop contributed largely to the total LER depending on the location where the experiment was set.

CONCLUSION

There are yield advantages from sweetpotato-maize intercropping systems in Uganda. The intercrop maize populations of 41,666 (density 1) and 55,555 (density 2) plants ha^{-1} give higher yields of the two crops than sole sweetpotato and maize populations, and are recommended to give farmers meaningful yield gains from the two nutritious crops, having diets rich in both vitamin A and proteins; while making better use of land and labour. Unfortunately, the same intercropping systems seem to affect root content of β-carotene in sweetpotato, i.e. β-carotene reduces with increasing intercropping plant populations. Maize plants reduce light interception by the sweetpotato, which results in reduced β-carotene biosynthesis, and hence, its content in the roots. However, we recommend that varieties with relatively high β-carotene be selected for intercropping and that lower plant densities of the component crop, especially the tall and aggressive crops, should be used to minimise shading on the growing sweetpotato. Further studies need to be conducted under controlled experiments to elucidate the effect of shading on β-carotene content in sweetpotato roots. This study further confirms the high yielding potential of variety NASPOT 9 O compared to Ejumula and illustrates that NASPOT 9 O performs better than Ejumula when intercropped with maize.

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