



Original Research Article

Assessing sweetpotato-legume intensification for improved productivity and land use efficiency in Malawi

Received 14 August, 2025

Revised 12 September, 2025

Accepted 17 September, 2025

Published 02 January, 2026

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The integration of sweetpotato (*Ipomoea batatas* (L.) Lam) with legumes provides innovative cropping systems that enhance land use, crop yields, soil health, and climate change adaptation among farmers in Malawi. Declining soil fertility, crop yields, and shrinking productive land continue to affect agricultural productivity and food security. Sustainable intensification of sweetpotato production is therefore essential. This study assessed sweetpotato-pigeonpea intensification options for productivity and land use efficiency in Malawi. Experiments were conducted at Chitedze, Baka, and Chitala during the 2020/2021 and 2021/2022 cropping seasons. Five spatial arrangements—(i) sole sweetpotato, (ii) sole pigeonpea (*Cajanus cajan* (L.)), (iii) sweetpotato-pigeonpea (1:1), (iv) sweetpotato-pigeonpea (2:1), and (v) sweetpotato-pigeonpea within row (SP-PP_row)—were evaluated using a randomized complete block design in a split-plot arrangement with three replications. Analysis of variance was performed, and means were separated by LSD_{0.05}. Land equivalent ratio (LER) and Absolute Mixture Effect (AME) were used to determine productivity. Cropping systems, locations, and seasons significantly influenced all measured parameters. Intercropping is more productive than sole cropping, with LERs exceeding one (LER > 1), indicating a yield advantage. The 1:1 and 2:1 arrangements showed the highest yield advantages of 3.57 and 2.55 tha⁻¹ above sole cropping, contributing 71% and 31% to total land productivity, respectively. Sweetpotato-pigeonpea intercropping enhanced land use efficiency, productivity, and pest and disease suppression, offering potential to improve food security, dietary diversity, and farmer incomes. The 1:1 and 2:1 arrangements are recommended for sustainable and productive farming systems in Malawi.

Keywords: Sweetpotato - legume, intercropping, pigeonpea, productivity, yield, land use efficient

INTRODUCTION

In Malawi, sweetpotato is one of the most grown crops in smallholder farms. Its widespread production is often attributed to its adaptive capacity to climate change, contributions to food and nutrition security, animal feed, and income generation (Low et al. (2009); Felistus et al. (2018). The crop is drought-tolerant with a short harvesting period of 3-5 months, hence providing an alternative crop in the face of unreliable and changing weather patterns (Motsa,

2015). It is rich in carbohydrates, proteins, calcium, iron, potassium, carotenoids, dietary fiber, and vitamins (Bovell-Benjamin, 2007). The production, consumption, and commercialization of sweetpotato have grown steadily in recent years and it has become a more important food crop in Malawi (Miyazaki et al. (2013). Despite the growing importance of the crop and the critical role it plays in household food and nutrition security, its productivity of

12 tons/ha remains low and current production systems remain non-competitive (Gatto et al., 2021). The average root yield obtained by farmers is by far lower than the potential yields of 35 tons/ha of recently released improved varieties (Vugt et al., 2018). Poor soil fertility, lack of storage technology, use of local varieties and declining land holding sizes are the main constraints contributing to the low productivity of sweetpotato in Malawi (GoM, 2008).

Pigeonpea is an important legume crop in Malawi, due to its high nutritive value and ability to survive various biotic and abiotic stresses. Its cultivation spans across marginal land mostly under rainfed situations where the risk of crop failure is very high. It is a drought-tolerant, deep-rooted, slow-growing plant; its seeds are used for feed and after harvesting the plants are cut and used for fuel (Jadav et al., 2020). This legume also improves soil fertility and yields of associated cereal crops through biological nitrogen (N) fixation, nutrient pumping and incorporation of green manure (Jadav et al., 2020). To protect crop failures and maximize food harvests over time and space, most farmers grow pigeon pea as intercrop with short-duration cereals and other crops.

Declining soil health, crop yields, climate change, and shrinking productive agricultural land are significantly impacting agricultural productivity and food security in Malawi. The dwindling land holding sizes, now at 0.4 ha per household (FAO, 2023), would further push the production of most crops into more marginal fields, resulting in the low productivity and environmental degradation (Vargas et al., 2016). The situation calls for farming systems that can sustainably intensify production in the face of declining soil fertility and increasing pressure on agricultural land.

Intercropping systems have been documented to offer numerous benefits including an increase in total crop yield, more efficient use of land and natural resources, soil health improvement, controlling weeds, insects and diseases (Paul et al., 2023); Katuromunda et al. (2021); Demie et al. (2022). These benefits can be attributed to more efficient use of land and natural resources, such as light, water, and nutrients, reduction of pest and disease as companion crops serve as barriers for pest and disease transmission (Stomph et al., 2020); Zhang et al., 2017).

Previous studies have reported that integration of root and tuber crops with legume exhibited higher land-saving efficiency, productivity, reduced competition, and stronger complementarity compared to cereal + legume systems (Adam et al., 2025). This highlights the potential of root and tuber crops + legume intercropping systems in improving household food security, enhancing intercropping productivity such as land equivalent ratio (LER) and promoting land-saving practices compared to cereal-legume intercropping systems. Despite the significant potential of root and tuber crops-legume intercropping in improving food and nutrition security, most previous studies on intercropping systems have focused primarily on cereal-legume intercropping, and often overlooked root and tuber crops, which are important to food security among smallholder farmers in Africa.

In Malawi, the integration of root and tuber crops with

legumes, particularly sweetpotato with pigeonpea has been identified as one of the innovative cropping systems that could achieve food and nutrition security, income generation and soil fertility improvement (NAIP, 2018). In terms of nutrition, intercropping sweetpotato with legumes, especially Orange-fleshed sweetpotato varieties, would generate foods that are nutrient-dense and essential for diet diversification and nutrition security (Snapp and Silim, 2002). Sweetpotato and legumes are compatible and have limited competition for nutrients, contribute to biological nitrogen fixation, and provide both protein and carbohydrate-rich food to smallholder farmers' households (Abidin et al., 2015). However, in Malawi, integration of legumes into sweetpotato-based farming systems has not received much attention as compared to maize-legumes intercropping (Abidin et al., 2015). It has been observed in some areas that farmers informally interplant sweetpotato with other crops such as pigeonpea and maize but there has not been extensive research on the efficiency and productivity of these systems. However, intercropping requires careful consideration of spatial patterns to minimize competition and maximize complementarity, which maximizes resource use (Duchene et al., 2017). Therefore, this study focused on assessing sweetpotato – legumes intensification options on productivity and land use efficiency in Malawi.

MATERIALS AND METHODS

Description of study sites

The on-station experiments were conducted across three agricultural research stations representing three contrasting agro-ecological zones in Malawi. The sites include: Chitedze, Chitala and Baka Agricultural Research Stations. Chitedze Research Station represents the mid-elevation upland plateau at 760–1300 meters above sea level (m.a.s.l). Chitala Research Station represents the lake shore, middle and upper Shire at an elevation of 200–760 masl. At the same time, Baka is located 2km west of Karonga at latitude 09° 54'S and longitude 33° 56'E with an elevation ranging from 460 meters above sea level. At Chitedze research station, the trial was established at longitude 13°59'S, 33°38'E, altitude of 1153 m.a.s.l. At Chitala, the trial was established at 13°40'S and a longitude of 34°15'E, at an elevation ranging from 525 to 650 meters above sea level. In Malawi, the mid-altitude agroecology lies between 600-1415 m.a.s.l with a mean annual rainfall of 600-1420mm. Low-altitude agroecology is located between 50-600 m.a.s.l with mean annual rainfall of 500-600 mm. The high-altitude agroecology is located above 1200 meters above sea level (m.a.s.l) with mean annual rainfall above 1200 mm (Figure 1).

Soil sampling and analysis

Before the experimental setup, soil samples were collected from all three sites at a depth of 0-30 cm using a soil auger. The soil samples were collected randomly in a W-shaped

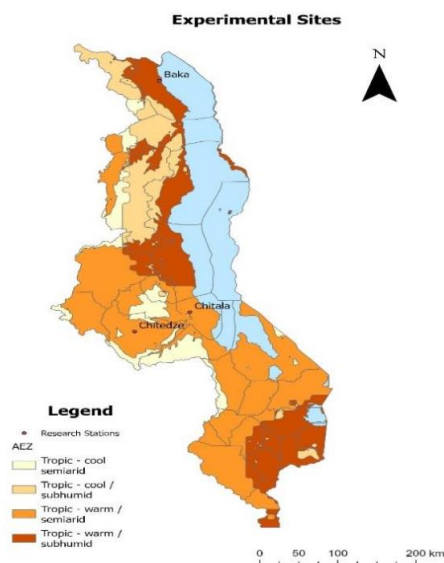


Figure 1: Map showing the experimental sites

pattern from the whole experimental plots. From this mixture, a 1.0 kg sample was taken and replicated 3 times for analysis. Before analysis, the soil sample was air-dried and sieved through a 2 mm sieve mesh. The composite soil sample was analyzed for selected physicochemical properties, including textural analysis (sand, silt, and clay), soil pH, total nitrogen (N), organic matter content, organic carbon, available phosphorus (P), calcium concentration (Ca), and exchangeable potassium (K) using the standard laboratory procedures.

Experimental setup

The experiment which consisted of five spatial crop arrangements namely, (i) sweetpotato sole crop (Sole SP), (ii) pigeonpea sole crop (Sole PP), (iii) alternating one row of sweetpotato with one row of pigeonpea (SP-PP-1:1), (iv) alternating two rows of sweetpotato with one row of pigeonpea (SP-PP-2:1); and v) sweetpotato - pigeonpea within-row interplanting (SP-PP-Row) was laid out using a randomized complete block design in a split-plot arrangement with three replications. The plot consisted of eight ridges of 5.0m in length with a spacing of 0.75 m between ridges. Within-row spacing for sweetpotato plants was 0.3m while pigeonpea was planted at 0.9m within ridges. The experiment utilized the Kadyaubwelere sweetpotato variety and Mwaiwathualimi pigeonpea variety.

Data collection and analysis

The data were collected from the net plots for all the treatments. Data collected including the number of marketable roots, number of non-marketable roots, weight of marketable roots, weight of non-marketable roots; and

number of weevil-infested roots; were collected on sweetpotato. Roots were harvested and separated into marketable (> 100 g) and non-marketable (< 100 g) sizes. In addition to the root size, marketability was determined based on farmers' assessment of whether they would be able to sell the roots on the local fresh root market or not. The number of roots and total weight of marketable and non-marketable roots were recorded separately. The total number of weevil-infested roots was recorded in each plot. Weevil infestation was identified by dark scarred spots on the root surface where weevils penetrated to feed on the roots. For pigeonpea, data were collected on the number of pods per 5 plants, plant height(cm), grain yield(kg), 1000 grain weight(g) and shelling percentage. The data collected were subjected to analysis of variance in GenStat 22nd Edition and means were separated by the least significant difference (LSD_{0.05}). For both crops, the factors were cropping seasons, locations, spatial arrangements and their interactive effects.

Land equivalent ratios

In this study, pLERs and LERs were used to measure the productivity of various crop combinations. LER compares the land required to grow a sole crop to the land required under intercropping, at the same level of management, to achieve the same economic output. The partial LER indicates which component crop of the intercropping is more competitive than the other in exploiting resources. To calculate LER, the yields of intercropped crops are divided by the net yield of each component crop, and the results are added together (Equation 1):

$$LER = \frac{Y_1}{M_1} + \frac{Y_2}{M_2} \dots\dots\dots \text{Equation 1}$$

In this case, Y_1 and Y_2 are the yields of intercrop of sweetpotato and pigeonpea; M_1 and M_2 are the yields of the monocrops of sweetpotato and pigeonpea. An LER > 1.0 indicates an advantage in intercropping, while an LER < 1.0 indicates a disadvantage in intercropping. A LER > 1, intercropping is more efficient than monocropping. An LER of 1.0 means that the land area required to grow a component crop in an intercrop is the same as when growing a component crop in a pure stand (Pankou et al., 2022); Moutier et al. (2022); Bedoussac et al. (2015); Zhang, (2025); Assefa et al. (2025); Fu, (2023).

Absolute Mixture Effect (AME)

The Absolute Mixture Effect (AME) was used to calculate the difference between the observed grain yield in the mixture and the average grain yield under the monoculture (Elsalahy et al., 2021); Demie et al. (2022); Paul et al. (2023); Paul et al. (2024) for sweetpotato and pigeonpea. The sum of the AME of sweetpotato and pigeonpea (Eqs. 1 and 2) was used to calculate the total AME in the mixture for both cultivars by using Eq. (3).

AME sweetpotato = sweetptato mix - (sweetpotato mono/2)

Table 1. Levels of key soil properties for the experimental fields across the three research stations

Properties	Depth	Site			Critical value
		Chitedze	Baka	Chitala	
pH	0-20	5.65	6.1	6.29	5.2
	20-40	6.05	5.8	6.41	
% OC	0-20	1.83	1.09	1.12	0.8
	20-40	1.65	0.64	0.99	
%OM	0-20	1.99	1.14	1.92	0.87
	20-40	1.78	0.99	1.71	
%N	0-20	0.16	0.09	0.08	0.1
	20-40	0.14	0.05	0.06	
P (ug/g)	0-20	3.28	27.3	20.36	13
	20-40	1.34	14.03	9.26	
K (Cmol/Kg)	0-20	0.01	0.04	0.03	0.2
	20-40	0.01	0.06	0.06	
Ca (Cmol/Kg)	0-21	0.51	0.91	0.85	0.2
	20-41	0.58	0.95	0.95	
% Clay	0-22	13	7	4	
	20-42	11	9	8	
% Silt	0-23	12	18	10	
	20-43	10	14	6	
Tex. Class	0-20	Sandy Loam	Loamy Sand	Loamy Sand	
	20-40	Sandy Loam	Sandy Loam	Loamy Sand	

Critical soil test values used; pH =5.2, OC =0.8%; N = 0.1%, P mg kg⁻¹, K = 0.2 Cmol/kg, CA 0.2 Cmol/kg (Snapp, 1998)

AME pigeonpea = pigeonpea mix - (pigeonpea mono/2)

AME = AMEsweetpotato + AME pigeonpea

The Absolute Mixture Effect (AME) in intercropping is a method for quantifying how the combined yield of crops in an intercrop system differs from the average yield of the same crops grown separately in monocultures. Therefore, in this study, we deployed AME.

RESULTS

Physiochemical properties of the soil of the experimental sites

The results of the soil analysis at the experimental sites before planting are presented in Table 1. The soils were found to be moderately acidic with a pH value ranging from 5.65 to 6.41. Furthermore, organic carbon was observed to be generally low in many of the sites except in Chitala research station where the values exceeded the critical value. The results also show low organic matter in one of the experimental sites, however, the values obtained from Chitedze and Chitala research stations were relatively above the critical values.

Sweetpotato yield and its characteristics

Sweetpotato growing conditions on vine yield and root characteristics across the three locations

The results of the effects of seasons, spatial arrangements, locations on the vine yield and root as well as their

interactions shown in Table 2. They significantly affected many of the parameters measured. The response of sweetpotato to different cropping arrangements across locations differed significantly for vine yield (tha⁻¹), number of marketable roots (tha⁻¹), number of non-marketable root (ha⁻¹), weight of non-marketable (tha⁻¹), weight of marketable roots (tha⁻¹), and total root weight (tha⁻¹) (Table 2).

Sweetpotato vine weights (tha⁻¹) under different cropping arrangements

The results of the analysis of sweetpotato vine yield are shown in Table 3. The results show that sweetpotato vine weights varied significantly ($P < 0.05$) across cropping systems, season and locations. Across locations, vine weights ranged from 16.56 tha⁻¹ for sweetpotato sole cropping at Chitedze during the 2021/2022 cropping season to 1.9 tha⁻¹ for SP-PP_row at the same location in the 2020/2021 cropping season. Vine weights were significantly higher in sole cropping than in the intercrops except for SP-PP-1:1 which recorded significantly higher vine weights at Chitedze in the 2020/2021 cropping season. Comparing the two seasons, sweetpotato vine weights were generally higher at the Chitala and Chitedze locations during the 2021-22 season as compared to the 2020-21 season. At Baka, in 2020-21, the sweetpotato sole cropping gave the highest vine weights of 15.30 tha⁻¹ and followed closely by SP-PP_row, having the total vine weights of 9.35 tha⁻¹. The trend was similar in the 2021-22 season with sole cropping having the highest vine weights of 13.62 tha⁻¹ while SP-PP_row recorded the lowest value of 2.48 t/ha.

Table 2: Sources of variation due to locations, seasons, cropping systems and their interactive effects on weight of marketable (WMR) and non-marketable roots (WNMR), Total root weight (TRW), Vine yield (VY), Number of marketable (NMR) and number of non-marketable roots (NNMR), Partial land equivalent ratio (pLER) across the three locations during the 2020/2021 and 2021/2022 cropping seasons

SOV	DF	WMR	WNMR	TRW	VY	NMR	NNMR	pLER
Cropping System (CS)	3	220.33***	13.22***	334.57***	88.59***	1536119916.93***	2176220650.87***	47.56***
Site	2	384.73***	13.79***	543.18***	11.36***	350430958.08***	766733097.59***	492.63***
Season	1	70.43***	2.28***	98.05***	440.34***	3044313052.86***	855719979.16***	120.21***
Cropping System X location	6	30.23***	0.44***	28.08***	17.43**	327912253.36***	144602518.37***	12.96***
Cropping System X season	3	6.65***	1.56***	12.60***	37.65***	32869113.18***	87596774.18***	7.49***
Site X Season	2	15.46***	7.01**	43.14***	240.36***	1349934274.18***	2014685765.28***	21.71***
C. System X Site X Season	6	2.94***	0.62***	3.72***	13.14***	180411302.16***	173856128.95**	3.46***
Residual	48	0.07	0.04	0.13	0.22	445491.91	302460.06	0.07***

*, **, *** Significant at 0.05, 0.01, 0.001, respectively, ns=not significant, SOV= Source of variation, DF=Degrees of freedom, WMR=Weight of marketable roots, WNMR= Weight of non-marketable root, TRW=Total root weight, VY=Vine yield, NMR=Number of marketable root, NNMR=Number of non-marketable root, pLER=Partial land equivalent ratio

Table 3. Mean vine yield (t ha⁻¹) of sweet potato intercropped with pigeonpea across three locations during the 2020/2021 and 2021/2022 cropping seasons

Cropping system	2020/2021 Season			2021/2022 Season		
	Baka	Chitala	Chitedze	Baka	Chitala	Chitedze
Sole SP	15.30 a	4.67 a	2.93 c	13.62 a	17.54 a	16.56 a
SP-PP-1:1	8.556 c	4.06 b	5.03 a	5.45 c	9.52c	10.92 b
SP-PP-2:1	8.41 c	3.82 b	4.26 b	10.62 b	14.65 b	11.05 b
SP-PP_row	9.35 b	4.36 ab	1.96 d	2.48 d	9.58c	10.08 b
Mean	10.41	4.23	3.54	8.04	12.82	12.15
F. Prob	<0.001	0.06	<0.001	<0.001	<0.001	<0.001
CV %	2.8	7.70	5.10	4.1	5.00	6.20

Similarly, at Chitala, sweetpotato sole cropping recorded the highest vine weights of 4.67 tha⁻¹ and was closely followed by SP-PP_row with total weights of 4.36 tha⁻¹ during the 2020-2021 season. Likewise, in the 2021-22 season, sole cropping gave the highest vine weights of 17.54 tha⁻¹ while intercrop (SP - PP 1:1) recorded the lowest value of 9.52 tha⁻¹. At Chitedze, the vine weights were generally low for all the cropping systems during the 2020-21 season with SP - PP 1:1 having the highest value of 5.03 tha⁻¹. However, in the 2021-22 season, vine yields were generally high for all the cropping systems. In comparison among the intercrops across locations and seasons, SP - PP (2:1) produced the highest vine weights of 14.65 tha⁻¹ in Chitala while SP-PP_row recorded the lowest vine

yields of 1.96 tha⁻¹ at Chitedze.

Number of marketable root ha⁻¹ of sweetpotato under different cropping systems

Figure 2 presents the number of marketable and non-marketable roots per hectare across three sites. The results reveal significant ($P < 0.005$) variations between cropping systems, seasons, and locations. The number of marketable roots was observed to be generally higher in sole cropping than in the intercrops.

Across cropping systems, locations and seasons, the number of marketable roots ranged from 52889 ha⁻¹ for sole cropping in Chitedze during 2020-21 cropping season to 5333ha⁻¹ for SP-PP-1:1 in Baka in 2021-22. The

number of marketable roots was generally high at Chitedze and Baka sites in 2020-21 and 2021-22 respectively. The results from Baka during the 2020-21 cropping season further reveal that sweetpotato sole cropping recorded the highest number of marketable roots of 32222 ha⁻¹, significantly higher than the values obtained from the intercrops. The same trend was observed in the 2021-22 season. Similarly, at Chitala, the number of marketable roots was significantly higher in sole cropping than in intercrops and it ranged from 32667ha⁻¹ for sole cropping in the 2020-21 season to 6778 ha⁻¹ for SP-PP1:1 in 2021-22. A similar trend was observed at Chitedze research station where sole cropping recorded the highest

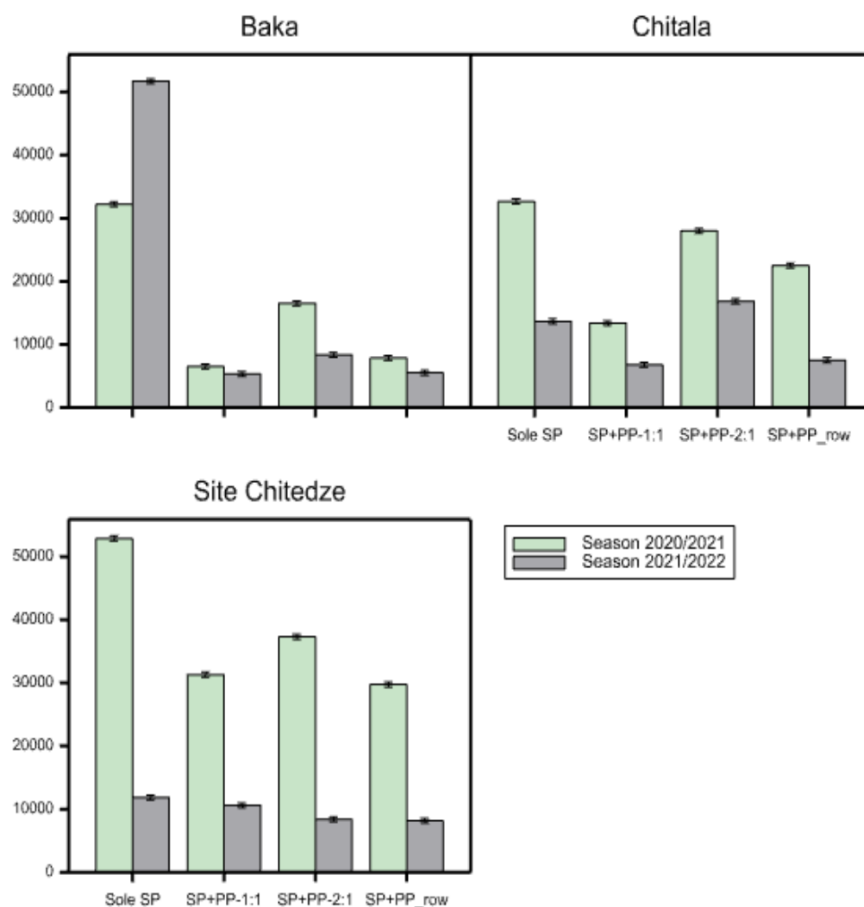


Figure 2: Number of marketable roots of sweet potato intercropped with pigeonpea across the three locations during the 2020/2021 and 2021/2022 cropping seasons

number of marketable roots for both seasons. Among the intercrops, SP - PP 2:1 recorded the highest number of marketable roots of 37296 ha⁻¹ at Chitedze in 2020-21 season and was closely followed by SP + PP 1:1 with 31296 ha⁻¹.

Number of non-marketable roots ha⁻¹ of sweetpotato under different cropping systems

Figure 3 presents the number of non-marketable roots per hectare across the three locations. Like the results of marketable roots, significant ($P < 0.005$) variations between cropping system, seasons, and sites were observed. The number of non-marketable roots was observed to be significantly higher in sole cropping than in the intercrops. It ranged from 58333ha⁻¹ for sole cropping at Chitedze during the 2020-21 to 4778 ha⁻¹ for SP-PP_row in Baka in 2020-21 season. Among the intercrops, SP-PP-2:1 recorded the highest number of non-marketable roots of 38519ha⁻¹ in Chitala during the 2021-22 cropping season and closely followed by SP-PP_row in Chitedze during 2020-21 cropping season while the least value of 4778 ha⁻¹ was recorded on SP-PP_row in Baka in the 2020-21. At Chitedze, the number

of non-marketable roots was generally higher in 2020-21 season than in the 2021-22 season.

The weight of marketable roots (tha⁻¹) of sweetpotato under different cropping systems

The results of the yield of marketable sweetpotato root under cropping systems are presented in Table 4. The results show that the weight of marketable roots was significantly affected by cropping systems, locations and seasons. It varies from 18.37 tha⁻¹ for sweetpotato sole cropping in Chitedze during the 2020-21 cropping season to 0.94tha⁻¹ for sweetpotato-pigeonpea in ratio 1:1 in Baka.

Across locations and seasons, the weights of marketable roots were significantly higher in sweetpotato sole cropping than in the corresponding intercrops. Sweetpotato sole cropping produced the highest weight of marketable roots of 18.37 tha⁻¹ at Chitedze during the 2020-21 cropping season. Comparison among the intercrops, SP-PP (2:1) recorded the highest weight of marketable roots of 14.73 tha⁻¹ at Chitedze during 2020-21 season. Conversely, SP-PP_row recorded the lowest values 0.86 tha⁻¹ and 0.94 tha⁻¹ respectively. Across the three sites, the weights of marketable roots were

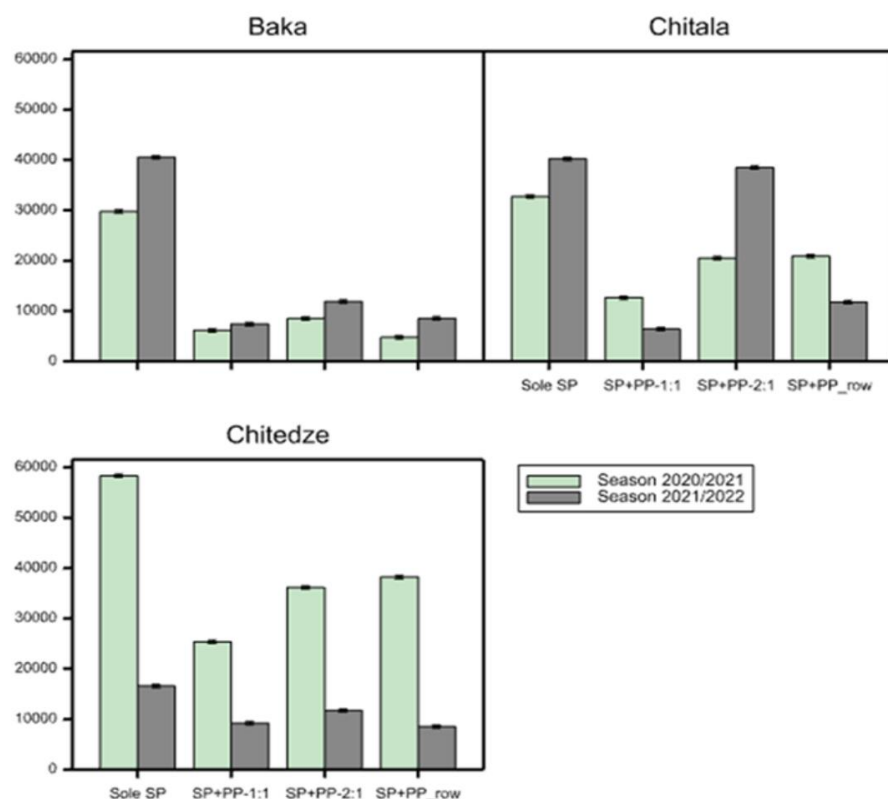


Figure 3: Number of non-marketable roots of sweet potato intercropped with pigeonpea across the three locations during the 2020/2021 and 2021/2022 cropping seasons

Table 4. Mean weight of marketable roots (t ha^{-1}) of sweet potato intercropped with pigeonpea across the three locations during the 2020/2021 and 2021/2022 cropping seasons

Cropping system	2020/2021 Season			2021/2022 Season		
	Baka	Chitala	Chitedze	Baka	Chitala	Chitedze
Sole SP	12.52 a	8.50 a	18.37 a	13.44 a	8.90 a	14.46 a
SP-PP-1:1	2.15 c	3.25 c	13.22 c	0.94 c	2.45 d	11.54 b
SP-PP-2:1	5.76 b	8.49 a	14.73 b	2.55 b	7.45 b	8.24 c
SP-PP_row	1.77 d	5.73 b	10.86 d	0.86 c	3.17 c	7.61 c
Mean	5.55	6.49	14.29	4.45	5.49	10.46
F. Prob	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CV %	2.9	4.20	1.50	3.4	6.10	3.90

generally high at Chitedze for both seasons. On a general note, intercropping significantly reduced the weight of marketable roots across the three sites.

The weights of non-marketable roots (tha^{-1}) of sweetpotato under different cropping systems.

Table 5 shows that the weights of non-marketable roots were affected significantly by cropping systems, seasons, and locations. The weights varied from 3.96tha^{-1} for sole cropping at Chitedze during the 2020-21 cropping season to $0.08 \cdot \text{tha}^{-1}$ for SP-PP within row at Baka during the 2021-22 season. Across locations, the results demonstrated that sole

cropping produced the highest weight (3.96tha^{-1}) of non-marketable roots which was significantly greater than those obtained from the intercrops. Interestingly, among the intercrops, SP-PP_row gave the highest weights of (3.65tha^{-1}) of non-marketable roots in Chitedze research during the 2020-21 cropping season.

Total root weight (t/ha) of sweetpotato under different cropping systems.

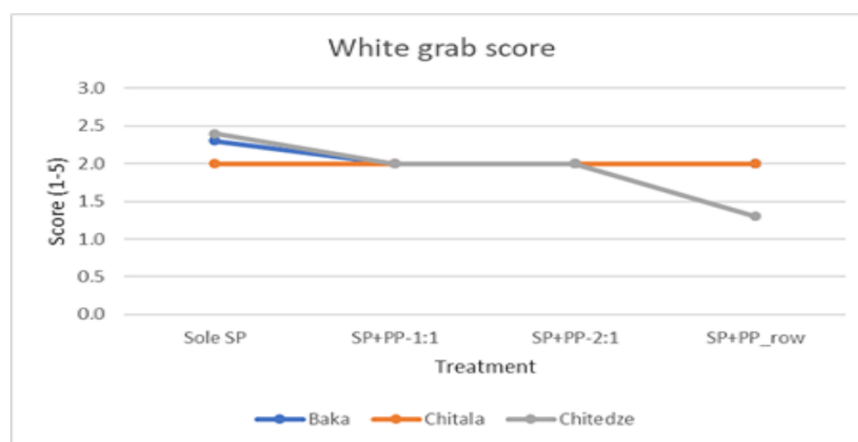
The total root weights(tha^{-1}) for sweetpotato are shown in Table 6. The result reveals that cropping system and sites significantly influenced the total root weight obtained from

Table 5. Mean weights of non-marketable roots (tha^{-1}) of sweet potato intercropped with pigeonpea across locations the locations during the 2020/2021 and 2021/2022 cropping seasons

Cropping system	2020/2021 Season			2021/2022 Season		
	Baka	Chitala	Chitedze	Baka	Chitala	Chitedze
Sole SP	1.63 a	1.61 a	3.96 a	2.41 a	3.50 a	2.72 a
SP-PP-1:1	0.41 c	0.51 c	1.70 c	0.31 bc	0.26 c	0.84 c
SP-PP-2:1	0.60 b	0.90 b	2.85 b	0.56 b	0.65 bc	1.27 b
SP-PP_row	0.29 d	0.76 bc	3.65 a	0.08 c	1.03 b	0.95 c
Mean	0.73	0.94	3.04	0.84	1.36	1.45
F. Prob	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CV %	7.6	20.10	8.40	27.8	17.20	7.40

Table 6. Mean total root weight (t ha^{-1}) of sweet potato intercropped with pigeonpea across the three locations during the 2020/2021 and 2021/2022 cropping seasons

Cropping system	2020/2021 Season			2021/2022 Season		
	Baka	Chitala	Chitedze	Baka	Chitala	Chitedze
Sole SP	14.15 a	10.11 a	22.33 a	15.85 a	12.40 a	17.18 a
SP-PP-1:1	2.57 c	3.76 d	14.92 c	1.25 c	2.72 d	12.38 b
SP-PP-2:1	6.36 b	9.39 b	17.58 b	3.11 b	8.10 b	9.51 c
SP-PP_row	2.06 d	6.49 c	14.50 c	0.94 c	4.20 c	8.56 d
Mean	6.28	7.44	17.33	5.29	6.85	11.91
F. Prob	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CV %	1.8	3.80	2.00	6.9	7.30	3.40

**Figure 4:** White grab score (1-5) of sweet potato intercropped with pigeonpea across the three locations during the 2020/2021 cropping seasons

sweetpotato sole cropping and its intercrops. Across locations and seasons, sweetpotato sole cropping significantly recorded high total root weights as compared to the intercrops. It ranged from 22.33 tha^{-1} for sole cropping at Chitedze during the 2021-21 cropping season to 0.94 tha^{-1} for sweetpotato intercropped within rows of pigeonpea in Baka during the 2021-22 cropping season. Comparison of different intercrops indicates that sweetpotato planted with pigeonpea in alternate rows of 2:1 in Chitedze gave the highest total root weight of 17.58 tha^{-1} during the 2020-21 cropping season and was significantly different from the values obtained from its corresponding intercrops with

alternate arrangement of 1:1 and SP-PP within row. Regardless of cropping system, total root weights were generally low in Baka and Chitala except for sole cropping which gave higher root yields across the three locations and seasons of evaluation.

White grab score (1-5) among sweetpotato-pigeon pea intercropping

The interactive effects of intercropping, location and season on white grab infestations are shown in Figure 4. The results showed that white grab infestation was significantly higher

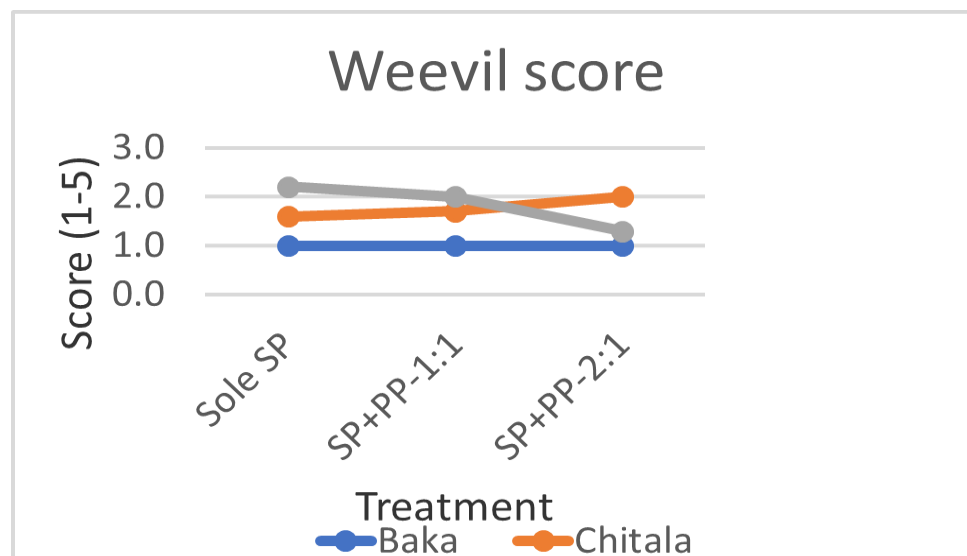


Figure 5: Weevil damage score (1-5) of sweet potato intercropped with pigeonpea across the three locations during the 2020/2021 cropping seasons

in sweetpotato sole cropping, having the highest infestations of 2.4 and 2.3 in Baka and Chitala respectively. On the other hand, no significant influence of the cropping system on white grab was observed in Chitala. Across locations, white grab infestations were relatively the same in all the cropping systems except for the sweetpotato planted within rows of pigeonpea that recorded the lowest infestation score of 1.3.

Weevil infestation (%) among sweetpotato-pigeonpea intercropping

Figure 5 presents the interactive effects of intercropping, location and season on percentage weevil infestation. The results showed that there was a significant influence of the cropping system on weevil attack in Baka and Chitedze. However, no significant difference was observed in Chitala as the values were at par across the cropping systems. Across location, sweetpotato sole cropping recorded the highest percentage of weevil infestations of 2.2% at Chitedze station. The results also reveal that weevil attack was generally low at Baka compared to Chitala and Chitedze stations.

Pigeonpea yield and its components

Pod weights of pigeonpea under sweetpotato cropping systems

The results of sweetpotato-pigeonpea intercropping on pod weights are shown in Table 7. The results show that pigeonpea pod weight was significantly influenced by cropping systems and varied across locations. The pod weight varies from 3885.19 kg ha⁻¹ for pigeonpea sole cropping in Baka to 600 kg ha⁻¹ for SP - PP (2:1) at Chitedze station. Across locations, the highest pod weights of 3885.19 kg ha⁻¹ were produced by pigeonpea sole cropping and

closely followed by SP - PP (1:1) that produced 3361.11 kg ha⁻¹ in Baka. Interestingly, pigeonpea produced more pod weight in the Baka research stations than Chitala (Table 7).

Pigeonpea grain yield (kg ha⁻¹) and shelling percentage under different cropping systems.

The results of pigeonpea grain weights and the shelling percentage are presented in Table 8 and 9 respectively. The results have shown that pigeonpea grain weights were significantly affected by cropping systems and sites. The grain yield ranges from 2196.30 kg ha⁻¹ for sole cropping in Baka to 202.22 kg ha⁻¹ in Chitala. Sole cropping recorded the highest grain yield values of 2196.30 kg ha⁻¹ in Baka and 546.30 kg ha⁻¹ in Chitedze. Surprisingly, pigeonpea sole cropping recorded the lowest value of 202.22 kg ha⁻¹ in Chitala. Among the intercrops, pigeonpea intercropped with sweetpotato in a ratio of 1:1 gave the highest grain yields of 2023.15 kg ha⁻¹ in Baka and closely followed by pigeonpea intercropped with sweetpotato in a ratio of 2:1 having a grain yield of 1825.93 kg ha⁻¹. Regardless of cropping system, pigeonpea grain yields were higher in Baka than in Chitala and Chitedze locations. Similarly, SP - PP _ row recorded the highest shelling percent (%) of 65.29 in Baka and was closely followed by SP - PP (1:1) with shelling percent (%) of 60.24. On the other hand, SP-PP _ row recorded the least value of 21.74. Interestingly, pigeonpea shelling percentage was generally higher in Baka than in Chitala and Chitedze research stations.

Pigeonpea 1000 grain weights(g) under different cropping systems

Table 10 presents the results of 1000 grain weights of pigeonpea when intercropped with sweet potato. The 1000

Table 7. Mean pod weight (kg ha⁻¹) of pigeonpea intercropped with sweetpotato across the three locations during the 2020/2021 cropping season

Cropping system	Pod weight (kg/ha)		
	Baka	Chitala	Chitedze
Sole PP	3885.19 a	907.41 b	1424.07 a
SP-PP 1:1	3361.11 b	968.52 b	764.81 b
SP-PP 2:1	3214.81 c	1485.19 a	600 c
SP-PP_row	2846.30 d	1490.74 a	756.48 b
Mean	3326.85	1212.96	886.34
F. Prob	<0.001	<0.001	<0.001
CV %	2.30	5.70	4.10

Table 8. Mean grain weight (kg ha⁻¹) of pigeonpea intercropped with sweetpotato across the three locations during the 2020/2021 cropping season.

Cropping system	Grain weight (kg/ha)		
	Baka	Chitala	Chitedze
Sole PP	2196.30 a	202.22 d	546.30 a
SP-PP 1:1	2023.15 b	270.37 c	313.52 b
SP-PP 2:1	1825.93 c	481.48 a	267.59 b
SP-PP row	1857.96 c	324.07 b	287.96 b
Mean	1975.83	319.54	353.84
F. Prob	<0.001	<0.001	<0.001
CV %	2.70	3.70	10.10

Table 9. Mean shelling percent (%) of pigeonpea intercropped with sweet potato across the three locations during the 2020/2021 cropping season.

Cropping system	Shelling percent (%)		
	Baka	Chitala	Chitedze
Sole PP	56.54 b	22.34 c	38.39 b
SP-PP 1:1	60.24 b	27.93 b	41.02 ab
SP-PP 2:1	56.81 b	32.59 a	44.71 a
SP-PP row	65.29 a	21.74 c	38.07 b
Mean	59.72	26.15	40.55
F. Prob	0.002	<0.001	0.101
CV %	3.40	7.40	7.70

Table 10. Weight of 1000 seeds (g) of pigeonpea intercropped with sweet potato across the three locations during the 2020/2021 cropping season.

Cropping system	Weight of 1000 seeds (g)		
	Baka	Chitala	Chitedze
Sole PP	87.62 d	95.44 b	94.23 d
SP-PP 1:1	100.41 c	110.15 a	123.74 a
SP-PP 2:1	115.71 a	106.91 a	106.63 b
SP-PP row	102.91 b	104.79 ab	103.34 c
Mean	101.66	104.32	106.98
F. Prob	<0.001	0.043	<0.001
CV %	0.90	5.00	0.80

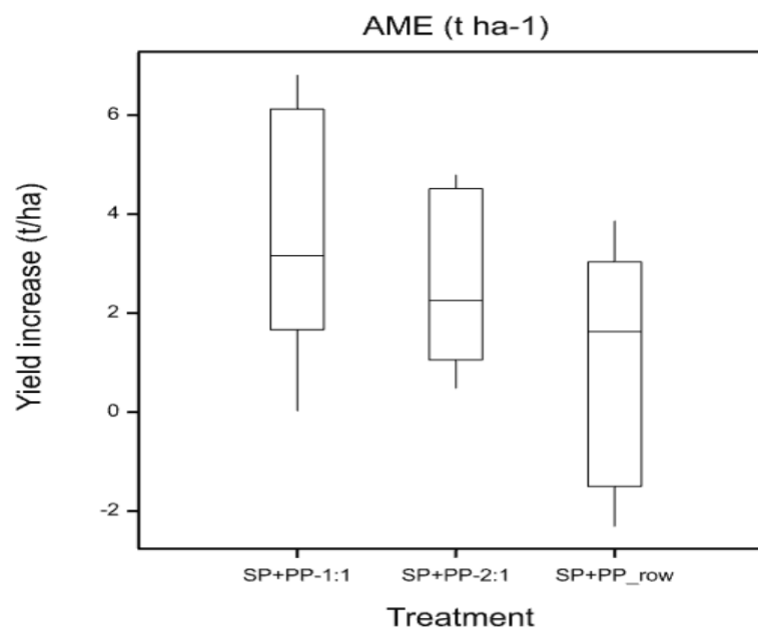
grain weights range from 123.74g in SP - PP (1:1) at Chitedze to 87.62g in sole pigeon pea at Baka. Across locations, SP - PP (1:1) recorded the highest value of 123.74g while the lowest value of 87.62g was recorded on sole pigeon pea cropping at Baka. Interestingly, pigeonpea grains were heavier at Chitedze than in Baka research station.

Partial and Total Land Equivalent Ratio (LER and pLER) of sweetpotato – pigeon pea intercropping

Table 11 presents the results of partial land equivalent ratio (pLER) and Land equivalent ratio (LER) of sweetpotato-pigeonpea intercropping across three locations in

Table 11. Partial Land Equivalent Ratio (pLER) and Land Equivalent Ratio (LER) of Pigeonpea-sweet potato intercropping during the 2020/2021 cropping season

Cropping system	pLERs		LERs
	Sweetpotato	Pigeonpea	
Baka			
SP-PP-1:1	0.48	0.93	1.41
SP-PP-2:1	0.45	0.84	1.29
SP-PP_row	0.15	0.86	1.01
Chitala			
SP-PP-1:1	0.37	1.34	1.71
SP-PP-2:1	0.63	0.68	1.31
SP-PP_row	0.64	0.6	1.24
Chitedze			
SP-PP-1:1	0.67	0.78	1.45
SP-PP-2:1	0.79	0.49	1.28
SP-PP_row	0.65	0.53	1.18

**Figure 6:** AME results showing yield advantage of sweetpotato – pigeonpea intercrops across the three locations during 2021/2022 seasons

2021/2022 and 2022/2023 cropping seasons. The results indicate a significant higher yield advantage in sweetpotato + pigeonpea intercropping compared to sole cropping. In all cases, the LERs were greater than one ($LER > 1$) indicating high land use efficiency and productivity of intercropping over sole cropping of sweetpotato and pigeonpea. Comparison among intercrops indicates that the highest total LER of 1.71 was recorded on Sweetpotato - pigeon pea (1:1) in Chitala, followed by Sweetpotato - pigeon pea (2:1) with 1.45 in Chitedze. Interestingly, across the three locations, land equivalent ratios (LERs) were generally positive for all the spatial arrangements. It was also noted that the contributions of sweetpotato and pigeonpea to the LER were not at the same levels. The land equivalent ratios

were generally high for both sweetpotato intercropped with pigeon pea in ratios (1:1) and (2:1) across the three locations.

The pLER values indicated that in Baka, sweetpotato contributed 0.48 in SP-PP (1:1), 0.45 in SP-PP-(2:1) and 0.15% in SP-PP_row to total productivity while the remaining 0.93 in SP-PP (1:1), 0.84 in SP-PP (2:1) and 0.86 in SP-PP_row came from pigeonpea. Similarly, at Chitala, sweetpotato contributed 0.37 in SP-PP (1:1), 0.63 in SP-PP (2:1) and 0.64 in SP-PP_row to the total productivity while 1.34 in SP-PP-1:1, 0.68 in SP+PP (2:1), and 0.6 SP-PP_row was contributed by pigeonpea. A similar trend was also observed at Chitedze. The pLER values of pigeonpea were higher at Baka than in Chitala and Chitedze (Table 11). The

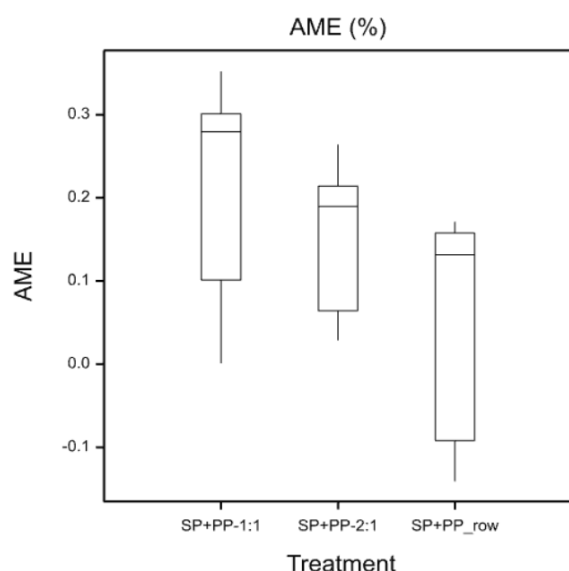


Figure 7: AME results showing percentage contribution to total productivity of sweetpotato – pigeonpea intercrops across the three locations during 2021/2022 season

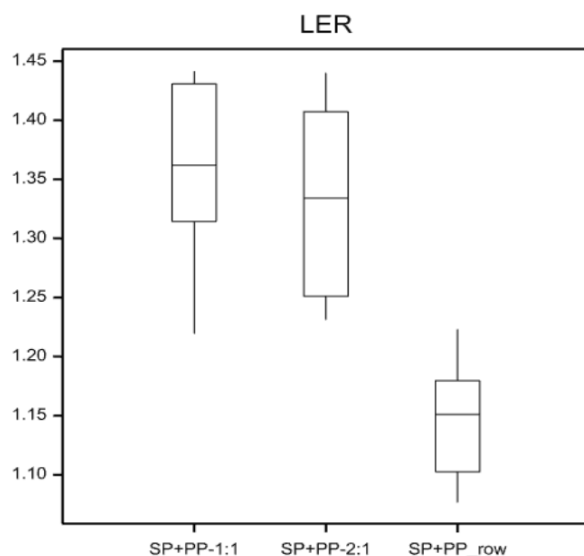


Figure 8: LER results showing percentage contribution to total productivity of sweetpotato – pigeonpea intercrops across the three locations during 2021/2022 seasons

PLER values of pigeonpea were highest at Baka (>0.8) compared with those at Chitedze and Chitala under the same systems.

Absolute Mixture Effect (AME) and LER for sweetpotato-pigeonpea intercropping across the three locations

The results of AME in Figures 6 and 7 show that sweet potato – pigeon pea intercrops are more productive than sole cropping as they recorded a significant yield increase above

the sole cropping. Across locations, sweet potato – pigeon pea (1:1) had the highest yield increase of 3.57 t ha^{-1} above the sole cropping and contributed to an average productivity of 22%. Also, sweetpotato – pigeonpea (2:1) was on average 15% more productive than sole cropping and had a yield increase of 2.55 t ha^{-1} compared to sole cropping. However, sweet potato – pigeon pea within row had the lowest yield advantage of 0.95 t ha^{-1} and contributed marginally (0.05%) to the total productivity. Similarly, the results of LERs indicate a significantly higher Yield increase in sweetpotato – pigeonpea intercropping compared to the sole sweetpotato cropping as indicated by LER. Across the three locations, sweetpotato - pigeonpea (1:1) recorded the highest LER of 1.36 and closely followed by sweetpotato - pigeonpea (2:1), having LER of 1.33 while the lowest value of 1.15 was recorded on sweetpotato – pigeonpea within row (Figure 8).

DISCUSSION

The significant effects of cropping system, sites, and seasons observed on sweetpotato vine yield (t/ha), number of non-marketable roots/ ha , number of marketable roots/ ha , total number of roots/ ha , weight of marketable (tha^{-1}), weight of non-marketable roots (tha^{-1}), and total root weight (tha^{-1}) in this study indicate a high level of variability across the cropping systems, seasons and study sites. The results align with the findings of Pankou et al. (2022) and Mansaray et al. (2022) who reported that growing seasons, treatments and their interactions significantly affected the performance and productivity of intercropping systems. Sweetpotato vine weights were significantly higher in sole sweetpotato than in the intercrops across sites and seasons. Sweetpotato sole cropping consistently gave higher vine weights than the intercrops at Baka and Chitedze for both seasons of the study. This observation might be attributed to the absence of shading effects on sole cropping plots, where crops were exposed to full sunlight throughout the growing period, enhancing their ability to intercept maximum light for photosynthesis and biomass accumulation. However, under the intercropping systems, there was a degree of interplant competition for sunlight, nutrients and water due to the shading effect of pigeonpea which reduced sweetpotato's ability to intercept light and other resources required for vegetative growth.

The variation in growth parameters is in line with Munda et al. (2019), who reported variations in the growth and yield of sweetpotato, groundnuts and soybean when they evaluated the effect of intercropping and phosphorus application in Mozambique. Egbe and Osang (2015) also observed higher folder weight in sole cropping than in intercropping when they evaluated the intercrop advantage of sweetpotato and soybean in Makurdi, Nigeria. The result also agrees with the findings of Idoko et al. (2018) who reported significant variation in plant heights and stem girth in sole cassava compared to when it was intercropped with maize. Katurumunda et al. (2021) and Senkoro et al. (2018) also observed better performance of potato varieties

under the sole potato cropping system than when intercropped with maize. The Katurumunda et al; (2021) reported that the observed variations could be attributed to less intra-plant competition for sunlight, water, soil nutrients, and air under the sole cropping as compared to intercropping.

Similarly, the results of the number of marketable and non-marketable roots of sweetpotato indicate a significantly higher number of marketable and non-marketable roots in sole sweetpotato cropping compared to intercropping systems. The significantly higher number of marketable and non-marketable roots observed under the sole sweetpotato cropping compared to intercropping can be attributed to the greater availability of sunlight on sweetpotato plants throughout the growing period. This enhanced full canopy development, root formation, and bulking, ultimately resulting in a higher root number due to greater interception of solar radiation and increased photosynthetic activity. Whereas, under the intercropping system, there was intra-plant competition between sweetpotato and pigeonpea for sunlight, water, soil nutrients, and air which may have affected their canopy development and prematurely reduced their photosynthetic activity due to shading of pigeonpea, especially during the tuber initiation stage that requires adequate availability of above and below ground resources for optimum photosynthetic activity and dry matter accumulation. Egbe and Osang (2015) and Idoko et al. (2018) reported similar results that intercropping reduced the number of marketable and non-marketable roots in their separate sweetpotato intercropping studies. These results are also in conformity with the findings of Mansaray et al. (2022) and Katurumunda et al. (2021) who observed significant reduction in yield and yield-related components of cassava and sweetpotato under different intercropping systems.

They attributed the observed variations to both inter- and intraspecific competition for growth resources such as light, water, and nutrients among the intercrop components. Bar-Anyam et al. (2019) also reported reductions in the total fresh root yield of sweetpotato varieties intercropped with pigeonpea and sorghum, respectively, and attributed this to a reduction in photosynthesis caused by decreased solar radiation due to shading of the sweetpotato. It can also be concluded that reduced availability of essential growth factors may have contributed to the decline in the weights of marketable and non-marketable roots in the sweetpotato intercrops.

The results revealed that pigeonpea grain yield was significantly influenced by cropping system, site and season of the study. Sole cropping recorded the highest grain yields, which were significantly higher than those obtained from sweetpotato-pigeonpea intercrops. The superior performance of sole pigeonpea cropping for many of the traits measured was consistent across locations and years of the study. The superior performance of sole pigeonpea compared to intercropping may be attributed to the complete absence of intra-plant competition in sole cropping, compared to the presence of both inter- and intra-plant competition in intercropping. Moreover, the sole

pigeonpea plant can grow well and form full canopy due to high photosynthetic activity and biological nitrogen fixation with adequate solar radiation. This is consistent with the work of Sauti et al. (2001) when they studied the performance of sweetpotato varieties with maize and sorghum intercrops in Malawi. These authors reported that the growth of non-legume crop was severely suppressed due to the depression of photosynthesis through decreases in irradiance. Egbe and Idoko (2012) observed similar results when they studied the relative performance of three sweetpotato varieties in sweetpotato-pigeonpea intercropping systems in Southern Guinea savanna ecology of Nigeria. Similar results were also observed by Bar-Anyam et al. (2019), who examined the productivity of sweet potato-sorghum intercrops in relation to different sweet potato cultivars and the timing of sorghum introduction in Nigeria.

The results of partial land equivalent ratio (pLERs) and Land equivalent ratio (LER) of sweetpotato intercropped with pigeonpea indicate significant yield advantage and land use efficiency in sweetpotato intercropped with pigeonpea compared to the sole sweetpotato cropping. In many cases, the LERs were greater than one ($LER > 1$) indicating yield advantage of intercropping over sole cropping of sweetpotato or pigeonpea. These results confirm the findings of Demie et al. (2022) who reported that 85% of the LER data points of cereal/legume intercropping were greater than 1, while 15% of the specific cereal/legume cultivar combinations resulted in $LER < 1$ when a compilation of studies on the effects of cultivar intercropping was analyzed. According to Mansaray et al. (2022), the productivity obtained from this study can also be attributed to the beneficial effects of legumes in the intercrops that may have favoured sweetpotato crop. The beneficial effects of legumes stem from their ability to improve soil nitrogen and soil organic matter through nitrogen fixation and decomposition of plant residues. The results of AME and LER show that sweetpotato - pigeonpea intercrops are more productive than sole cropping as they recorded significant yield advantage above the sole cropping. Across locations, sweetpotato - pigeonpea (1:1) had the highest yield advantage of 3.57 t ha^{-1} above the sole cropping and contributed to an average productivity of 22%. Also, sweetpotato - pigeonpea (2:1) was 15% more productive than sole cropping and had a yield advantage of 2.55 t ha^{-1} than sole cropping. However, sweetpotato - pigeonpea within row had the lowest yield advantage of 0.95 t ha^{-1} and contributed marginally (0.05%) to the total productivity. Similarly, the results of LERs indicate a significantly higher yield increase in sweetpotato - pigeonpea intercropping compared to the sole sweetpotato cropping as indicated by LER. Across the three locations, sweetpotato - pigeonpea (1:1) recorded the highest LER of 1.36 and closely followed by sweetpotato - pigeonpea (2:1), having LER of 1.33 while the lowest value of 1.15 was recorded on sweetpotato - pigeonpea within row. These results agree with the earlier findings of Demie et al. (2022) and Paul et al. (2023), who reported that intercropping is a more efficient cropping system than sole cropping. However, this study confirmed

that the magnitude of these yield advantages depends on different factors such as cropping arrangements, seasons, and environments as different intercropping options respond differently to varying environments and seasons as indicated by LERs.

CONCLUSION

This study has provided scientific insights that sweetpotato can be successfully intercropped with pigeonpea and that this intercropping system not only offers the yield advantages of intercropping but also enhances optimal utilization of available environmental resources. Compared to sole sweetpotato cropping, the intercropping of sweetpotato with pigeonpea resulted in significantly higher yield as indicated by LER and AME. All the intercrops gave higher LERs that were greater than one ($LER > 1$), indicating yield advantage of intercropping over sole cropping of sweetpotato or pigeonpea. Comparison among intercrops indicated that the highest total LER was recorded on Sweetpotato - pigeonpea (1:1) and Sweetpotato - pigeonpea (2:1). It was also noted that pigeonpea tended to dominate sweetpotato in Baka, as indicated by the partial LERs. Sweetpotato – pigeonpea (1:1) and (2:1) were found to be more advantageous in comparison with sole cropping and could be promoted in Malawi for sustainable and productive farming systems. Future research should integrate, varietal selection, economic profitability and long-term soil fertility impacts.

Authorship contribution statement

GA contributed to the study conceptualization, design, methodology, investigation, data curation, funding acquisition, project administration, supervision and writing of the original draft. HC contributed to methodology, design, investigation, supervision, data collection, analysis and review. OM was involved in design, methodology, investigation, data collection and review. AP contributed to the design, methodology and trial supervision. MN contributed to data collection, data cleaning, analysis and review. WJ contributed to the funding of acquisition, project administration, supervision, review and editing. The first draft of the manuscript was written by GA, and all authors commented on the first versions of the manuscript. All authors read and approved of the final manuscript.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that no Generative AI was used in the creation of this manuscript.

Funding

The author(s) declare that financial support for this research and the publication of this article was received from the European Union (EU) under the DeSIRA Program: Development-Smart Innovation through Research in Agriculture (DeSIRA) project in Malawi. Grant: FOOD/2019/413-081

ACKNOWLEDGEMENTS

The authors are grateful to the European Union (EU) who funded this study and the International Potato Center (CIP) for offering an environment for its successful implementation. The authors' gratitude also goes to the Department of Agricultural Research Services (DARS) who supported the establishment and monitoring of field experiments.

REFERENCES

- Abidin F, Chipungu T, Nyekanyeka T, Chilanga O, Mwenye J, Kazembe B, Botha E, Carey E. (2015): Potato and sweetpotato in Africa: transforming the value chains for food and nutrition security pp. 405-413 [CrossRef](#)
- Adam AM, Giller KE, Rusinamhodzi L, Rasche F, Koomson E, Marohn C, Cadisch G (2025): Enhancing the resilience of intercropping systems to changing moisture conditions in Africa through the integration of grain legumes: A meta-analysis: Field Crops Research. 2025 Feb 1;321:109663. [CrossRef](#)
- Assefa A, Abate M, Haile M, Hunegnaw Y (2025). Land productivity and economic benefit of sorghum (*Sorghum bicolor* L.), mung bean (*Vigna radiata* L.) intercropping using intercrop indices and Partial budget analysis in Lasta District, North Eastern Ethiopia. Discover Plants, 2(1), 153. [CrossRef](#)
- Bar-Anyam MN, Idoko JA, Obasi MO (2019): Productivity of sweet Potato/Sorghum Intercrop as influenced by Sweet Potato cultivars and time of introducing sorghum in Southern Guinea Savanna, Nigeria PAT December 15 (2):108-117
- Bedoussac L, Journet EP, Hauggaard-Nielsen H, Naudin C, Corre-Hellou G, Jensen ES (2015). Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. Agron. Sustain. Dev. 35, 911–935. doi: [CrossRef](#)
- Bovell-Benjamin AC (2007): Sweet Potato: A Review of Its Past, Present, and Future Role in Human Nutrition. Advances in Food and Nutrition Res., 52, 1-59. [CrossRef](#)
- Demie DT, Döring TF, Finckh MR, van der Werf W, Enjalbert cereal/legume intercropping. Front. Plant Sci., 13 (846720).

- <https://www.Front.Org./Artic./> [CrossRef](#)
- Duchene O, Vian JF, Celette F (2017): Intercropping with legume for agroecological cropping systems: complementarity and facilitation processes and the importance of soil microorganisms. A review. *Agr. Ecosyst. Environ.* 240 148–161. [CrossRef](#)
- Egbe MO, Osang PO (2015): Intercrop advantages of some improved sweet potato + soybean in Makurdi, Benue State, Nigeria. *International Letters of Natural Sciences*, 39:28–39.
- Egbe OM, Idoko JA (2012): Evaluation of Pigeonpea Genotypes for Intercropping with Maize and Sorghum in Southern Guinea Savanna: Economic Benefits. *Int. J. Agric. Forestry*, 2:108–114. [CrossRef](#)
- Elsalahy H, Bellingrath-Kimura S, Kautz T, Doring T (2021). Effects of mixing two legume species at seedling stage under different environmental conditions. *PeerJ* 9, 10615. [CrossRef](#)
- FAO (2023): Food and Agriculture Organization of the United Nations – Production: Crops and livestock products
- Felistus C, Wisdom C, Aggrey A, John S, Nzola M, Jonathan M (2018): Adaptation of sweet potato [*Ipomoea batatas* (L.) Lam] genotypes in various agro-ecological zones of Malawi. *Afri. J. Biotechnol.* 17(16):531–540. [CrossRef](#)
- Fu ZC (2023). Maize-legume intercropping achieves yield advantages by improving leaf functions and dry matter partition. *BMC Plant Biology*, 23(1), 438. [CrossRef](#)
- Gatto M, Okello J, Pradel W, Kwikiriza N, Chipungu F, Kapalasa E, Kumwenda W, Masikini L, Mgombezulu W, Nyirenda Z, Okuko H, Suarez V, van Vugt D, Hareau G, Heck S (2021). Adoption and Effects of Orange-fleshed Sweetpotato Varieties in Malawi. Lima, Peru: CGIAR Research Program on Roots, Tubers and Bananas. [CrossRef](#)
- GoM. (2008). Food security action plan. *Food security action plan Volume I MINISTRY*, (January).
- Idoko JJ, Oorlamen T Offordile AE (2018). Effect of intercropping some crop species with orange-flesh sweet potato varieties in Makurdi. *Int. J. Agric. Pol. Res.* 6 (3):28–37. [CrossRef](#)
- Jadav ML, Mishra KP, Mishra US, Pandey A (2020). Effect on yield, water use efficiency and economics of pigeon pea of mulch and irrigation under windhyan plateau of Madhya Pradesh. *Int. J. Curr. Microbiol. Appl. Sci.* 9(9):3525–3533
- Katuromunda S, Ekwaro B, Wanaku B (2021). Yield performance of newly developed cassava varieties in response to inorganic fertilizers. *Mod. Appl. Sci.* 15, 60. [CrossRef](#)
- Low JW, Lynam J, Lemaga B, Crissman C, Barker I, Thiele G, Namanda S, Wheatley C, Andrade M (2009). Sweetpotato in Sub-Saharan Africa. In: Loebenstein, G., Thottappilly, G. (Eds.), *The Sweetpotato*. Springer Science Business Media B.V, Dordrecht, pp. 359–390.
- Mansaray A, Karim AB, Yormah TB, Conteh AR, Yomeni M (2022). Effect of cassava-legume intercropping systems on productivity and cassava insect pests population dynamics across three major agro-climatic zones of Sierra Leone. *World J. Adv. Res. Rev.* 12(03):285–295. [CrossRef](#)
- Miyazaki H, Ishimoto Y, Tanaka U, Umetsu C (2013). the Role of the Sweet Potato in the Crop Diversification of Small-Scale Farmers in Southern Province, Zambia. *African Study Monographs*, 34(2):119–137.
- Motsa NM (2015). Sweet potato (*Ipomoea batatas* L.) as a drought tolerant and food security crop. *South Afr. J. Sci.* 111, 11/12 (Nov. 2015), 8. [CrossRef](#)
- Moutier N, Baranger A, Fall S, Hanocq E, Marget P, Floriot M, Gauffreteau A. (2022) Mixing Ability of Intercropped Wheat Varieties: Stability Across Environments and Tester Legume Species. *Front. Plant Sci.* 13:877791. [CrossRef](#)
- Munda E, Pieterse PJ, Andrade MI, Makunde GS, Pereira EI. (2019). Improving productivity of orange-fleshed
- National Agricultural Investment Plan (NAIP, 2018) Prioritized and Coordinated Agricultural Transformation Plan for Malawi: FY 2017/18–2022/23. Ministry of Agriculture, Irrigation and Water Development P.O. Box 30134 Lilongwe 3 Malawi
- Pankou C, Lithourgidis A, Menexes G, Dordas C (2022). Importance of Selection of Cultivars in Wheat–Pea Intercropping Systems for High Productivity. *Agronomy* 2022, 12, 2367. [CrossRef](#)
- Paul MR, Demie DT, Seidel SJ, Doring TF (2023). Effects of spring wheat / faba bean mixtures on early crop development. *Plant Soil.* [CrossRef](#)
- Paul, MR, Demie DT, Seidel SJ, Döring TF (2024). Evaluation of multiple spring wheat cultivars in diverse intercropping systems. *European J. Agron.* 152, 127024.
- Sauti RFN, Matabwa ES, Bakali DF, Braunnworth WS Jr. (1991). The performance of sweet potato varieties with maize and sorghum intercrops in Malawi [http: www.actahort.org/books/380/380_113.htm](http://www.actahort.org/books/380/380_113.htm)
- Senkoro CJ, Tetteh FM, Kibunja CN (2018). Cassava yield and economic response to fertilizer in Tanzania Kenya and Ghana. *Agronomy J.* 2018;110(4):1600–1606. [CrossRef](#)
- Snapp SS, Silim SN, (2002). Farmer preferences and legume intensification for low nutrient environments
- Stomph T, Dordas C, Baranger A, de Rijk J, Dong B, Evers J, Gu C, Li L, Simon J, Jensen ES (2020) Designing intercrops for high yield, yield stability and efficient use of resources: Are there principles? *Adv. Agron.* 160: 1–50.
- sweetpotato (*Ipomoea batatas*) through intercropping with legumes and moderate phosphorus application. *South African J. Plant Soil* 36(3):221–228
- Van Vugt, D, Franke, AC, Giller KE (2018). Understanding variability in the benefits of N₂-fixation in soybean-maize rotations on smallholder farmers' fields in Malawi. *Agriculture, Ecosystems and Environment*, 261(36):241–250. [CrossRef](#)
- Vargas R, Omuto C (2016) Malawi Soil Loss Assessment. Available from: [http:// unpei.org/sites/default/files/Soil Loss Assessment in Malawi](http://unpei.org/sites/default/files/Soil%20Loss%20Assessment%20in%20Malawi.pdf).
- Zhang H, Zeng F, Zou Z, Zhang Z, Li Y (2017). Nitrogen uptake and transfer in a soybean/maize intercropping system in the karst region of southwest China. *Ecol. Evol.* 7: 8419–8426.
- Zhang YS (2025). Intercropping maize and peanut under semi-arid conditions is a zero-sum game. *Field Crops Research*, 326, 109833. [CrossRef](#)

