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RESEARCH ARTICLE

Effect of combining organic manure and inorganic fertilisers on maize–bush bean intercropping

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Summary

In sub-Saharan Africa (SSA), farmers intercrop common beans with maize but apply inorganic or organic fertilisers targeting only maize. Effects of this practice on bush bean yield have not been fully evaluated with respect to input use and compatibility when intercropped with maize. An on-farm trial managed by smallholder community members was conducted to assess the influence of various soil fertility management options and cropping systems on the yield of two bush bean genotypes (SER45 and SER83) in two agro-ecological zones of Malawi. The farmer-managed trials were laid out in split-plot design, with the bean genotypes as main plots and a combination of the soil fertility management options (i.e., no input, manure, fertiliser and fertiliser + manure) and cropping systems (i.e., sole crop and intercrop) as subplots. The trials were affected by terminal drought and dry spells, but results show that manure and fertiliser application enhanced the resilience of the drought-tolerant bean genotypes. The genotype SER45 was responsive to manure application in the sole crop, giving a 44.4% yield increase over no-manure application. In sole cropping with fertiliser plus manure, bean yields improved by 40.1% for SER45 and 78.3% for SER83 relative to the no-input control. Although sole cropping had higher bean yields, the treatment with manure and fertiliser had a higher land equivalence ratio for intercrop of 1.54 for SER45 and 1.32 for SER83 over sole cropping. These results show that, under smallholder farmer management, the climate adaptability of bush bean genotypes could be enhanced by the combined application of organic and inorganic fertilisers in maize–bean intercrop. The combined application also enhances whole-farm productivity of the common maize–bean intercrop practice than monocrop, hence is of benefit to most low-input smallholder farmers of SSA.

Keywords: Cereal–legume cropping systems; Bush bean genotypes; Drought-tolerant bush bean; Organic manure; Inorganic fertiliser

Introduction

Maize–bean intercrop has been found to consistently increase land productivity by 20–150% compared to sole cropping (Alemayehu *et al.*, 2017; Bitew *et al.*, 2021; Kutu and Asiwe, 2010; Morgado and Willey, 2003; Ndungu-Magiroi *et al.*, 2017). Based on land equivalent ratios (LERs), farmers practicing intercrop utilise less land to produce the same amount of crop as is produced under sole cropping on a relatively larger land. Smallholder farmers in Malawi and elsewhere in sub-Saharan Africa (SSA) who have critically low land to produce food for home consumption and a little surplus for sale exploit this intercropping advantage. Studies have found that intercropping maximises the use of labour, environmental and financial resources while reducing Striga infestations of maize while contributing to soil fertility through biological nitrogen fixation (Nassary *et al.*, 2020; Silberg *et al.*, 2020). For the rural poor in eastern and southern Africa, common beans provide nutritional benefits to the cereal-dominated diet as beans are a cheap source of proteins and essential minerals (Monyo and Kananji, 2013; Nchimbi-Ms and Tryphone, 2010). A systematic review by Karavidas *et al.* (2022) established that most bean yield studies focused on breeding, irrigation and rhizobia treatment with effects of fertilisation (mostly inorganic fertilisers) and intercropping accounted for in 11 and 5% of the 250 sources reviewed, respectively. Most bean–maize intercrops are with climbing beans due to their canopy advantage, but a recent study by Nkhata *et al.* (2021) in Malawi found higher intercropping efficiencies for dwarf bean genotypes.

Earlier studies on nutrient use efficiency focused on maize (Fairhurst, 2012; Sanginga and Woomer, 2009; Sileshi *et al.*, 2019) because in bean–maize intercrop, farmers apply fertiliser targeting only the primary maize crop (Makumba *et al.*, 2012). Building on some earlier pioneering studies (Snapp *et al.*, 1998), there is growing evidence that fertilisation benefits both cereals and legumes in intercrops resulting in higher system productivity (Karavidas *et al.*, 2022; Kiwia *et al.*, 2019; Ndungu-Magiroi *et al.*, 2017). Intercrops have been shown to produce higher yields relative to monocrops even with limited application of inorganic fertiliser (Clermont-Dauphin *et al.*, 2003; Kiwia *et al.*, 2019; Rediet *et al.*, 2017). However, the combined effects of inorganic fertiliser and organic manure on the yield of bean genotypes have not been widely evaluated with respect to yield response and compatibility when intercropped with maize (Chichongue *et al.*, 2020; Lunze *et al.*, 2012). Some studies show that organic manure compromises bean yield due to potential immobilisation as mineralisation processes are manure quality-, weather- and soil-dependent (Karavidas *et al.*, 2022). However, studies in southern Africa found positive effects (Chichongue *et al.*, 2020), indicating that the manure effects vary across agro-ecological zones (AEZs).

In Malawi, common bean yields have been low, averaging 0.6 t ha^{-1} (Monyo and Kananji, 2013) relative to the yield potential of 1.0–2.5 t ha^{-1} under recommended management (Farrow and Muthoni-Andriatsitohaina, 2020; Muthoni *et al.*, 2008). The low productivity has been attributed to declining soil fertility, use of unimproved genotypes, non-use of good agronomic practices, climate variability, and increase in incidence and severity of pests and diseases (Beebe *et al.*, 2013; Monyo and Kananji, 2013; Mugendi *et al.*, 2011; *Wortmann et al.*, 1998). The use of improved genotypes is considered as a principal tool to optimise the productivity of common bean (Karavidas *et al.*, 2022), but about 70% of farmers in Malawi use local genotypes (Katungi *et al.*, 2012) and up to 90% of those using improved genotypes rely on recycled seed from local seed systems (Maereka and Rubyogo, 2020). However, access to improved bean genotypes has also proved to be a problem in SSA, including Malawi. In response to this, research has been on-going to both develop and aid the release of new and improved genotypes (Mwenda and Chirwa, 2007). Considering the frequent droughts experienced in Malawi, the International Centre for Tropical Agriculture (CIAT) developed drought-tolerant bean genotypes which were under testing and screening across different AEZs (CIAT, 2010). In this study, we explored an integrated suite of soil fertility management (ISFM) technologies that included the use of improved genotypes and inorganic and organic fertilisers adapted to the farming systems of intercropping or monocropping as a strategy for closing the bean yield gap.

The objectives of this study were to evaluate the effects of the use of: (1) chicken manure, inorganic fertiliser and the combination of the two, and (2) two cropping systems (i.e., sole cropping and intercropping with maize) on the yields of bush bean genotypes. Chicken manure was selected in this study as it is cheap and shown to be rich in P and N (Sileshi *et al.*, 2017), which are essential for the proper development of beans. With the rising costs in inorganic fertilisers, it would be the best alternative for smallholder farmers who have limited access to farm inputs.

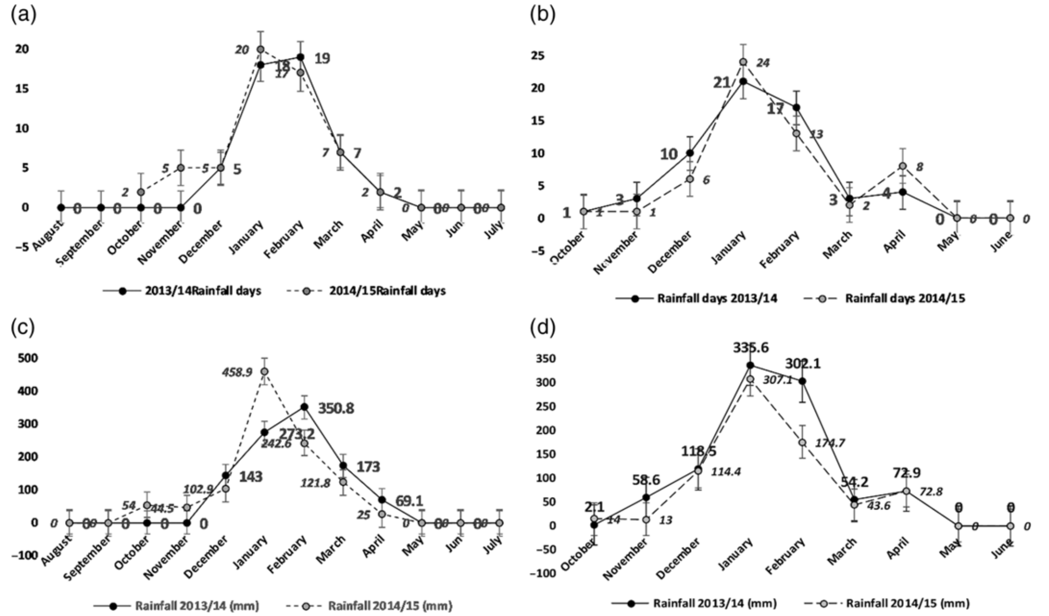

Figure 1. Monthly trends for rainfall days for (a) RV zone and (b) LL zone and total monthly rainfall for (c) RV zone and (d) LL zone.

Materials and Methods

Study area

The study was undertaken in Kandeu (Ntcheu District) and Linthipe (Dedza District) Extension Planning Areas in central Malawi representing rift valley (RV) escarpments and Lilongwe (LL) AEZs, respectively. The two zones are prime bean–maize intercrop areas in Malawi, with RV at elevation 900–950 m asl compared to LL at 1200–1300 m asl. During the study period, rainfall varied across the two zones. In the 2013–2014 season, the LL and RV received 944.0 and 1009.1 mm, whereas in 2014–2015 rainfall was 739.6 and 1049.7 mm, respectively. The monthly trends (Figure 1a and b) show similar rainfall days between 2013–2014 and 2014–2015 but with a prolonged dry spell towards the end of February–March.

At the commencement of the trials, baseline soil samples were collected based on the Land Degradation Surveillance Framework protocol (Vågen *et al.*, 2015). The soils in both zones were deficient in N (< 0.15%) and had moderate to high available P (>12 mg/kg), adequate K (> 70 mg/kg) and adequate soil organic carbon content in LL (> 2.0%) but deficient in the RV (< 2.0%) (Sommers *et al.*, 2013; Tamene *et al.*, 2019). The soils of LL are clay, whereas those of the RV zone were dominated by the clay loam (50%), followed by clay (30%) and finally sandy clay loam (20%). Since beans prefer loamy soil textures, the dominant loamy texture (70%) in the RV zone puts the site at an advantage in bean production, whereas the clay textural nature of LL zone soils is a potentially limiting factor for bean growth and development.

Study design, sampling, and treatments

This study is based on a participatory action research approach, in which communities managed on-farm trials for two seasons (2013–2016) as technology learning and adoption centres (Rippke *et al.*, 2016; Snapp, 2002). Six trials were set in different villages to facilitate participation as well as to capture landscape diversity. Each one of them – centrally located on one of the farmers'

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land – was managed by the community members and consisted of a complete set of ISFM technologies. Out of six community-managed trials that were set up in 2013–2014 season, only one in LL zone (site BM) was harvested while others failed due to terminal drought. In 2014–2015 season, although there was a dry spell around March, all the six were harvested.

The treatments were laid out in a split-plot design and replicated three times at each trial. The main plots at each trial included the two bean genotypes (SER45 and SER83), whereas the subplots were eight treatment combinations of cropping systems and different soil fertility management options: (1) sole beans (B); (2) beans + manure (Bc); (3) beans + manure + fertiliser (Bcf); (4) beans + maize (BM); (5) beans + maize + manure (BMc); (6) beans + maize + manure + fertiliser (BMcf); (7) beans + maize + fertiliser (BMf) and (8) maize + manure + fertiliser (Mcf).

For bean, we used two modern genotypes, namely SER45 and SER83, which were found to be consistently superior to existing improved genotypes in terms of tolerance to drought and aluminium toxicity, high-yield potential of 1.8–2.8 t ha^{-1} for SER45 and 1.5–3.3 t ha^{-1} for SER83, early maturing (60 days), and resistant to diseases such as anthracnose, rust, common bacterial blight (CBB) and bean common mosaic virus (BCMV) (Abate, 2012; CIAT, 2010; Dovala-Chicapa *et al.*, 2016; Palmer, 2016). A short-season hybrid (110–115 days), high-yielding maize variety with a potential yield range of 6–12 t ha^{-1} (Tamene *et al.*, 2016), DKC8033, was used in the bean–maize intercrop.

Each plot had five ridges spaced 0.75 m apart and 5 m long; a dead row was left between the plots to act as a path. In the intercrops, two bean plants were planted in between maize plants, both at the spacing of 0.30 m giving a plant population of 45 000 ha^{-1} for maize and 90 000 ha^{-1} for beans. In sole beans, one plant was planted per hole at the spacing of 15 cm, giving a plant population of 90 000 ha^{-1}. In 2013–2014 season, the trails were planted during the first week of December 2013. Beans were harvested during the second week of April, while maize was harvested during the last week of May 2014. In 2014–2015 season, the trials were planted during the first week of December 2014, beans were harvested during the first and second week of April 2015, while maize was harvested during the last week of April.

Fertiliser was applied at the rates recommendation for maize in Malawi and for beans in southern Africa (Mutegi *et al.*, 2015). In all fertilised plots, a compound fertiliser (23:21:0 + 4 S) was applied just after emergence at the rate of 23 kg N and 21 kg P_2O_5 ha^{-1}. In maize plots, top dressing with urea (46% N) at the rate of 92 kg N ha^{-1} was done 21 days after the maize planting date. Chicken manure was applied at the rate of 7 t ha^{-1} supplying 98 kg N, 112 kg P_2O_5 and 70 kg KO_2 ha^{-1}. Although farmers' own relatively fewer chicken, cumulative collection of chicken manure droppings over the dry season is of a considerable amount, for uniformity, we used manure procured from a large-scale poultry farm purchased at a price of US$ 1.0 per 50 kg.

Data collection and analysis

For both beans and maize, the number of plants in the net plot of 3 m × 3 m was counted and recorded. At crop maturity, five plants were randomly harvested by cutting at the base (Liu *et al.*, 2012; Pirbolouti *et al.*, 2006). For beans, the seeds from the five plants were counted and weighed, while for maize, the cobs were shelled, and the fresh weight of grains were determined. Then, samples were taken and oven-dried, and the yield was adjusted to 12.5%.

The efficiency of the intercropping system as compared to sole cropping was analysed using the land equivalent ratio (LER), which is a measure of land utilization benefits of intercrops over monocultures of each crop (Mead and Willey, 1980; Peksen and Gulumser, 2013). A linear mixed-effects model was used to analyse the effects of treatments on yield because it addresses the hierarchical nature of the split-plot design, imbalances in sample size, variance heterogeneity, and non-normality of errors through the inclusion of both fixed and random effects.

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Table 1. Effects of genotypes and soil fertility management on bush bean yield

Agro-ecological zone	Fixed term	Ndf	*F* statistic	Ddf	*F* probability
Lilongwe	Genotype	1	0.25	98.6	0.615
	Treatment	6	22.87	43.2	<0.001
	Genotype. Treatment	6	2.53	43.2	0.035
Rift valley	Genotype	1	1.02	78	0.315
	Treatment	6	6.15	44	<0.001
	Genotype. Treatment	6	1.38	44	0.243

Ndf = numerator degrees of freedom; Ddf = denominator degrees of freedom.

Table 2. Mean yield of bush bean genotypes across years and agro-ecological zones

Season	AEZ	Bean genotype	Trial site	Mean grain yield (t ha^{-1})	95% confidence intervals (t ha^{-1}) Lower	Upper
2013–2014	Lilongwe	SER45	BM	0.57	0.39	0.74
		SER83	BM	0.64	0.52	0.76
2014–2015	Lilongwe	SER45	BM	1.24	0.93	1.54
			EP	0.68	0.48	0.89
			LP	0.80	0.59	1.01
			Mean	0.91	0.67	1.14
		SER83	BM	1.10	0.77	1.42
			EP	0.64	0.47	0.81
			LP	0.96	0.76	1.16
			Mean	0.90	0.67	1.13
	Rift valley	SER45	FM	1.49	1.22	1.76
			CM	0.79	0.63	0.96
			LM	1.05	0.86	1.23
			Mean	1.11	0.90	1.32
		SER83	FM	1.25	1.06	1.43
			CM	0.98	0.83	1.13
			LM	1.33	1.12	1.54
			Mean	1.18	1.00	1.36

AEZ = agroecological zone; LL = Lilongwe AEZ; RV = rift valley AEZ; abbreviations BM-LM are trial sites.

The mean treatment yields were separated using the least significant differences. Bartlett's test of homogeneity of error variances between trial sites within zones was used to determine whether to combine the analyses across sites, and the Akaike information criterion was used as a measure of parsimony (i.e., the lower the value, the better the model fit).

Results

Bush bean yield

Linear mixed model analysis on aggregated trial sites in each zone revealed significant differences between the management options for both SER45 and SER83 in both districts (Table 1). The interaction effects between genotype and treatment were significant in LL zone but not in RV zone. This implies that response to management options were genotype-specific in the LL zone but not in the RV zone. Bartlett's test of homogeneity of variances between trial sites was significant for both the LL zone ($\chi^2 = 12.60$; $p < 0.05$) and the RV zone ($\chi^2 = 6.13$; $p < 0.05$), implying inequality of the variances between the AEZs.

Response of beans to the management options was significantly different except in a few instances (Table 2). In most sites, the highest yields were observed in the combined treatment of manure and fertiliser (Bcf), followed by the treatment with manure only (Bc), while the most

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Table 3. Mean yield (t ha^{-1}) of bush bean genotypes treated with organic and inorganic fertilisers in maize–bean intercrop vs. sole cropping

		Lilongwe plain agro-ecological zone				Rift valley escarpments agro-eco zone		
Genotype	Treatment	BM2014	BM2015	EP2015	LP2015	CM2015	FM2015	LM2015
SER45	B	0.60 bc	0.93 ab	0.78 b	1.02 cd	0.93 a	0.78 abc	1.00
	Bc	0.57 bc	1.35 bcde	1.97 ef	0.99 bcd	2.01 ef	1.97 ef	1.21
	Bcf	NA	1.54 de	2.13 f	1.19 d	1.33 abcd	2.13 f	1.09
	BM	1.08 d	0.75 a	0.37 a	0.27 ab	1.03 ab	0.37 a	0.41
	BMc	0.36 ab	1.01 abcd	1.09 c	0.44 ab	1.60 cd	1.09 bcd	0.42
	BMcf	0.21 a	0.93 ab	1.38 cd	0.61 abc	2.23 f	1.38 cde	0.60
	BMf	0.59 bc	0.81 ab	0.94 b	0.24 ab	1.29 abcd	0.94 abcd	0.85
SER83	B	0.57 bc	1.06 abcd	0.53 ab	0.41 ab	1.61 de	0.53 ab	1.01
	Bc	0.59 bc	1.51 cde	1.66 de	1.09 d	1.24 abc	1.66 def	0.73
	Bcf	NA	1.85 e	2.29 f	1.19 d	1.40 cd	2.29 f	1.40
	BM	0.52 ab	1.08 abcd	0.25 a	0.22 a	0.94 a	0.25 a	0.65
	BMc	0.90 cd	1.01abcd	1.24 cd	0.71 abcd	1.05 ab	1.24 cd	1.05
	BMcf	0.88 cd	1.83 e	0.97 bc	0.49 abc	1.36 bcd	0.96 abcd	1.15
	BMf	0.35 ab	0.95 abc	0.75 b	0.30 ab	1.11 ab	0.75 abc	0.86
	CV	36.1	27.9	36.6	39.8	28.6	25.6	25.6
	LSD $0.05_{\%}$	0.35	0.56	0.44	0.56	0.40	0.63	
	Significance	**	**	**	**	**	**	NS

LSD = least significant differences, NA = treatment not included; NS = not significant; CV= coefficient of variation.
**$p < 0.05$, means with same letters are not significantly different.
Treatment (B = bean; c = chicken manure; f = inorganic fertiliser, M = maize); abbreviations BMyyyy-LMyyyy are trial sites.

least yield values were for the control treatment of beans–maize intercrop without fertilisation (BM).

Across the two seasons, using the time series data from the trial managed under BM, a significantly lower overall bean grain yield was obtained in the 2013–2014 season of 0.57 [0.39–0.74] t ha^{-1} against 1.02 [0.93–1.54] t ha-1 in 2014–2015 season, translating into a 69.7% yield difference (Table 2). Across AEZs, the results for 2014–2015 season show that the two genotypes performed equally in terms of grain yields. Within trial sites, SER45 performed significantly lower only under the EP management than the BM.

In each AEZ, significant differences were noted between the management options for both SER45 and SER83 (Table 3 and Figure 2). The interaction effects between genotype and treatments were significant only in the LL, indicating that responses to management options were genotype-specific in LL and not in the RV zone.

Response of beans to different management options was significantly different between treatments for the two genotypes at the two zones, except for management site LM (Table 3). At most trial sites, the highest yields were observed in the treatment Bcf, which comprised sole beans treated with a combination of manure and fertiliser, followed by the treatment Bc. The least yield values in yield were mostly observed in the option unfertilised BM intercropped. This trend was consistent at most trial sites except under the management of the CM community. As expected, sole cropped beans had, on average, significantly higher grain yields of 1.211 and 1.164 t ha^{-1} than those under intercrop of 0.767 and 0.868 t ha^{-1} for SER45 and SER83, respectively. Under sole cropping, the highest mean yield for the two seasons was obtained in the bush bean genotype SER45 (1.211 t ha^{-1}), followed by SER83 (1.164 t ha^{-1}) (Figure 2).

Chicken manure had significant effects on the yield of both SER45 and SER83 with yield increases of 36.5% (0.275 t ha^{-1}) and 41.5% (0.308 t ha^{-1}), respectively, compared to the no-input control (Table 3). The interaction effects between genotype, cropping system and manure

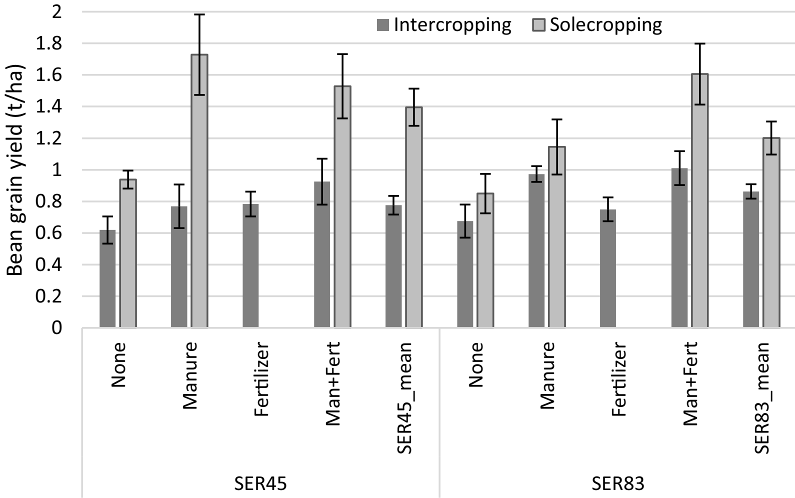

Figure 2. Main and interaction effects of manure and inorganic fertilisers on yield of SER45 and SER83 bean genotypes under sole and in intercrop with maize.

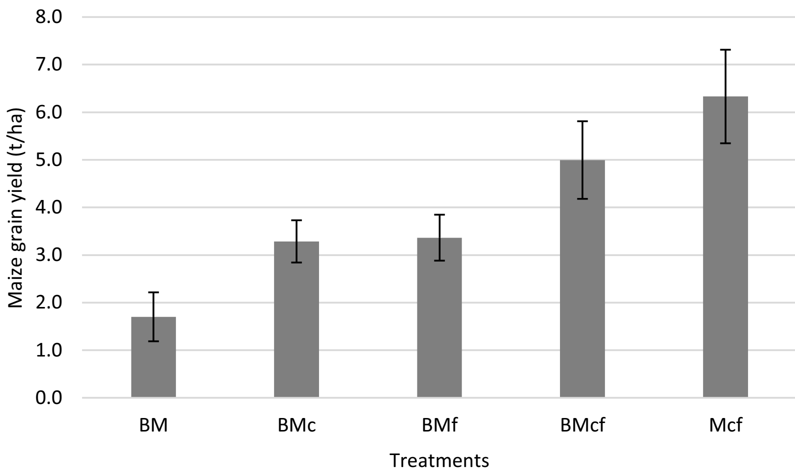

Figure 3. Effects of different management options on maize yield. NB: Treatments (B = bean; c = chicken manure; f = inorganic fertiliser, M = maize).

application were significant for SER45, with an increase of about 44.4% (0.4 t ha^{-1}) compared with no-input control. The yield difference was insignificant for SER83.

Maize yield and LERs

Across zones, sites and years, manure and inorganic fertiliser had a significant effect on maize grain yield (Figure 3). Maize yield of 1.7 t ha^{-1} in a control of unfertilised BM intercrop was significantly lower than all other treatments. Manure increased maize yield in maize–bean intercrop to 3.2 t ha^{-1} which was comparable with yields from the inorganic fertiliser treatment. Combination of manure and inorganic fertiliser increased the yield of DKC8033 to its potential range of 5.0 t ha^{-1} in intercrop and 6.3 t ha^{-1} under sole cropping.

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Table 4. Land equivalent ratios for maize–bush bean intercrop treated with organic and inorganic fertiliser

	SER45			SER83		
Treatments	Maize (mg/ha)	Bean (mg/ha)	LER	Maize (mg/ha)	Bean (mg/ha)	LER
Bcf	0	1.47	1.54	0	1.61	1.32
BMcf	5.40	0.95		4.59	1.07	
Mcf	6.09	0		6.93	0	
PLER	0.89	0.65		0.66	0.66	

PLER = partial land equivalent ratio; treatments: B = bean, c = chicken manure, f = fertiliser, M = maize; LER = land equivalent ratio.

The results show a comparative advantage of intercrop over either sole bean or sole maize (Table 4). The partial LERs show that both maize and bush bean yields are affected in intercrop. The LER for the combined treatment of organic manure and inorganic fertiliser has a higher LER of >1.0 for both bean genotypes. In the intercrops, the treatment with manure and fertilizer combination had higher land equivalence ratios of 1.84 for SER45 and 2.01 for SER83 over sole cropping. The results indicate the overall system advantage of intercropping bush beans with maize (DKC8033) under combined treatment of organic and inorganic fertiliser.

Discussion

Bush beans are sensitive and susceptible to extreme moisture content; droughts (prolonged dry conditions) or extreme wetness negatively affect the yield (Farrow and Muthoni-Andriatsitohaina, 2020). The trials encountered extreme environmental stresses: high rainfall followed by terminal drought or dry spells. Disease score on the ordinal scale of prevalence (1–9) in the two seasons (2013–2014 and 2014–2015) showed that both varieties in both sites had a low prevalence of angular leaf spot (1–2), BCMV (1), anthracnose (1), CBB (1), rust (1) and web blight (2–3). The high rainfall in December–February is conducive for WB, and the slight susceptibility of both SER45 and SER83 to WB resulted in heavy infestation in the RV zone in the 2013–2014 season, wiping out about 60% of the crop but its lower than the potential infestations recorded of up to 90% (Allen *et al.*, 1996). In addition, beans grow well in soils that are deep, loamy and well drained, with no deficiencies (Long *et al.*, 2010; Navazio *et al.*, 2007). Extreme moisture content in the soil during the vegetative stages of bush beans could have interfered with the overall development of the crop.

In spite of these extreme climatic effects, soil treatment with organic manure boosted performance. Organic manure is one of the climate-smart agricultural interventions as the addition of organic matter rejuvenates the ailing health of soils emanating from overuse (Satyajeet *et al.*, 2007; Zingore, 2006). As in our results, positive responses by beans to manure application were observed by Silwana *et al.* (2007). The baseline soil N was limited as beans in general require about 36 kg N ha^{-1} at most, for optimum yields under proper management and good rainfall (Long *et al.*, 2010), with 20 kg N ha^{-1} as the acceptable minimum. Based on the application rates in this study, the N supplied by the fertiliser 23:21:0 + 4S (23 kg N ha^{-1}) and manure (98 kg N ha^{-1}) were above the minimum (>20 kg N ha^{-1}) and more than adequate (>36 kg N ha^{-1}) for beans, respectively. In the economically constrained farming systems of rural Africa, manure has the potential to provide plant nutrients and build soil health (Chilimba *et al.*, 2005)

In addition to mitigating climate variability and providing nitrogen, manure contributes significantly to phosphorus, another major plant nutrient. Although the baseline characterisation shows sufficient P content in highlands regions with high annual rainfall, available soil P has most often been deficient due to fixation by aluminium (Al), iron (Fe) and manganese (Mn) of acidic ultisols and oxisols. Farmers traditionally do not apply nutrients to beans; the crop requires an adequate supply of phosphorous for effective growth and development. Since microdosing with

P fertilisation is low, manure made from mostly crop residues and livestock has a complementary role (Chilimba *et al.*, 2005) and the combined usage has the potential to maintain P adequacy as P build-up (Maida, 2013). Ahmad and Arain (2021) observed that the integrated application of inorganic fertilisers and poultry manure significantly increased common bean yield as opposed to the application of inorganic fertiliser alone or manure alone.

Under sole cropping system, positive yield responses for both bean genotypes were observed when a combination of manure and inorganic fertilisers were used. This contrasts with when only manure was applied, in which SER45 responded positively (Figure 2). This suggests that other factors related to inherent differences in nutrient utilisation (most probably N, the observed limiting nutrient) between the genotypes were responsible for the differences in bean yield, not just the nutrient content. Studies have established that combining organic manure and inorganic fertilisers improves agronomic efficiency, translating into improved crop yields (Ahmad and Arain, 2021; Alley and Vanlauwe, 2009; Fairhurst, 2012). Manure provides active carbon in the soil which plays a significant role in the enhancement of nutrient cycling and availability (Chamberlin *et al.*, 2021)

With terminal drought and dry spells experienced in Malawi and the region, manure also enhances the soil water-holding capacity. Otieno *et al.* (2009) observed increased nodulation in treatments with manure, unlike those with just inorganic fertilisers. This suggested that the relatively higher yields in sole beans with a component of manure were most likely due to enhanced moisture retention (observations made in 2014–2015 between treatments with manure component and those without), working synergistically with the positive effects of manure on nodulation of beans. Relative to its effect on maize, fertiliser plus manure treatment did not influence bean yield in the maize–bean intercrops (Table 4), owing to intra-specific competition, where beans are generally outcompeted by maize. Notably, maize has higher competitive abilities for nutrients than beans under a bean–maize intercrop (Ogutu and Owuoche, 2012). As such, higher yields in pure stands could be attributed to a lack of competition for nutrients, water and other environmental resources. There was, however, an exception in SER83, where a positive response was registered when both manure and fertilisers were applied under intercrop with maize. The lack of significant differences between the two genotypes under intercrop and sole cropping revealed their equal performance within the cropping systems. A combination of fertiliser and manure was found to give higher maize yields than fertiliser only, attributed to increased agronomic efficiency due to the combined application of fertiliser and manure.

The LER was greater than 1 for both SER45 and SER83, signifying better land use efficiency of the maize-bush bean intercrop. This is consistent with other studies showing that intercropping of maize with bush bean achieves higher LER values (Abera *et al.*, 2005). The LER of 1.84 and 2.01 for SER45 and SER83 suggests that there is 84 and 101% greater land area requirement for the monoculture system relative the intercrops. These findings suggest that land utilization advantages derived from maize and bush bean intercropping will depend on the variety used.

Conclusion

The results show that bean genotypes performed consistently across two contrasting AEZs and within trial sites under different managements by the mother trial community groups. The findings further show that various cropping systems and soil fertility management options affect the yield of bush bean genotypes. Yields under intercrop were lower than those under bean sole crop. It is concluded that the use of manure, inorganic fertilisers and their combination significantly improved yields of SER45. SER83 yielded a positive response only when both manure and fertiliser were applied. For maize, higher yields were associated with the application of inorganic fertiliser. LER for both SER45 and SER83 were >1.0, signifying better land use efficiency of the maize-bush bean intercrop. Therefore, the promotion of improved, drought-tolerant bean genotypes in combination with appropriate soil fertility management and cropping system options can increase bean productivity in Malawi.

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