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## INTEGRATION OF GRAIN LEGUMES AND *MBEYA* MANURE IMPROVES MAIZE PRODUCTIVITY ON SMALLHOLDER FARMS IN CENTRAL MALAWI

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## ABSTRACT

Legumes are integrated in maize-based systems to improve soil fertility and crop productivity. However, the ecosystem services from legumes vary. Crop rotation on-farm studies were conducted over two cropping seasons (2018/19 and 2019/20) in Mkanakhoti and Kaluluma Extension Planning Areas (EPAs) in Kasungu district, central Malawi. The main objective of this study was to evaluate maize response to legume cropping systems and *mbeya* manure. In the first season (2018/19), five treatments including sole groundnut (Gn), sole soybean (soy), sole pigeon pea (PP), and doubled-up legumes (legume + legume intercrop) - pigeon pea intercropped with groundnut (Gn+PP), and pigeon pea intercropped with soybean (Soy+PP) were grown. In the second season (2019/20), maize was planted on plots that had either sole or doubled-up legumes. These plots were split into two, one half was top dressed with 23kg N ha<sup>-1</sup> only and the other half received 23kg N ha<sup>-1</sup>+1000kg ha<sup>-1</sup> *mbeya* manure. The experiments were replicated in 2019/2020 and 2020/2021 seasons. Soil fertility was low and highly variable between farms in the study sites. Soil pH, total nitrogen (N), available phosphorus (P), organic matter (SOM) and active carbon in topsoil (0-15cm) averaged 5.1±0.5, 0.19±0.18%, 31±19.6 ppm, 1.4±0.34 %, and 193±74 mg kg<sup>-1</sup>, respectively. Application of *mbeya* manure to maize increased leaf chlorophyll and plant height (p<0.05). There were variations in maize yield responses to legumes with higher benefits obtained from maize rotated with doubled-up legumes than sole legumes. The results also showed that on non-responsive soils, overall, the use of *mbeya* manure in combination with legume systems increased the rotational maize grain yield by 88% over maize following legumes only (p<0.05), with highest yields from doubled up legumes/maize rotations followed by groundnut/maize rotations. It is therefore recommended that on highly degraded soils, farmers can increase maize productivity through integrated soil fertility management involving a combination of 23kg N/ha and 1000kg/ha of *mbeya* manure applied to maize rotated with doubled-up legumes (Gn+PP or Soy+PP) and sole groundnut (Gn).

**Key words:** Doubled-up legumes, crop rotation, groundnut, pigeon pea, soybean, maize, *mbeya* manure



## INTRODUCTION

Maize (*Zea mays*) is the most important source of human calories in sub-Saharan Africa, and absolutely plays a major part in solving Africa's food crisis, particularly in countries of Southern and Eastern Africa. Malawi is one of the countries in sub-Saharan Africa in which food security is generally defined in terms of adequate production of and access to maize, the country's staple crop [1]. Despite the role that maize play in food security, maize yields on smallholder farms are still low averaging less than 3 tons/ha [2, 3] compared to potential yield of 5000 to 15,000 kg ha<sup>-1</sup> for hybrid varieties, 3000 kg ha<sup>-1</sup> for local varieties, and 4500 to 8000kg ha<sup>-1</sup> for open pollinated varieties [4]. Low soil fertility is one of the major constraints to maize productivity. Nitrogen (N) is one of the limiting nutrients on smallholder farms in Malawi [5]. Legumes integration in farming systems is one of the strategies for addressing N limitations in farming due to their ability to biologically fix atmospheric N into inorganic forms that can be used by plants, and legumes are competitive for absorbing soil in-organic nitrogen which is fixed in the form (NH<sub>4</sub>) that can be used by plants [6, 7, 8]. Previous studies conducted in Malawi have shown that doubled-up legumes (pigeon pea intercropped with either groundnut or soybean) improve soil fertility and crop productivity under variable conditions in maize-based cropping systems [6, 9, 10, 11]. Additionally, these studies reported 12 to 77% variation on maize yield increment following sole and doubled up legumes. Further studies by Mhango *et al.* [12] reported the existence of highly degraded soils that were non-responsive to the legume cropping systems as a soil health option. The non-response with some soils might be because of their physical and chemical properties. Most of the soils in the study sites (Kaluluma and Mkanakhoti EPAs) are sandy with low organic carbon ranging from 0.9% to 1.4%, low moisture holding capacity, and low cation exchange capacity with an average of 1.57 cmol (+) kg<sup>-1</sup>. Additionally, most of the soils have a pH of < 5.2 [13]. These soil characteristics necessitated the need to investigate sustainable measures like use of *mbeya* manure which is an organic compound made by mixing ashes, chicken dung, urea fertilizer and maize bran applied in order to complement legumes that are integrated in cereal based cropping systems to improve soil fertility and crop productivity. This is complemented by Kahah *et al.* [14], who reported that adequate application of poultry manure reduced bulky density, increased total soil porosity, soil pH, total nitrogen, organic carbon, available phosphorus and cation exchange capacity (CEC). This study therefore was conducted to evaluate maize response to legume cropping systems and *mbeya* manure. The specific objectives were to assess the effects of sole and doubled-up legume systems and *mbeya* manure on plant growth, chlorophyll, maize grain yield, and yield components. It was hypothesized that on non-responsive soils, application of *mbeya* manure to maize following legumes will improve maize yield and yield components.



## MATERIALS AND METHODS

### Study site

The study was conducted in two extension planning areas (EPAs), namely Kaluluma (S 1243.729, E03327.325) and Mkanakhoti (S 1270.5084 and E 033624.396) located in Kasungu district, central Malawi. Kasungu district is in the mid agroecological zone, lies at an altitude of 600 to 1,300 meters above sea level (m.a.s.l) The area is characterized by moderate temperatures of 11 to 29°C and a rainy season of between 4 to 5 months, with average rainfall of about 875mm per annum [4].

### Rainfall pattern 2018/19 and 2019/20 cropping seasons

During the first cropping season (2018/19), the annual rainfall was 802mm and 813mm in Kaluluma extension planning area (EPA) and Mkanakhoti extension planning area (EPA), respectively. In 2019/20 season Kaluluma and Mkanakhoti EPAs received annual rainfall of 727mm and 782 mm, respectively and in 2020/21 season the EPAs had the annual rainfall of 756 mm and 743 mm, for Kaluluma and Mkanakhoti, respectively. In both EPAs, during the three seasons, the rainfall was adequate for maize growth and development. The highest rainfall was experienced in the 2018/19 season among the three seasons.

### Treatments

In the 2018/2019 cropping season, sole and intercropped legumes (soybean, groundnut, and pigeon pea) were grown. There were five treatments including sole groundnuts (Gn), sole soybean (soy), sole pigeon pea (PP), Gn + PP intercrop and soy + PP intercrop which were replicated into 40 plots. Each covered gross plot area of 10m x 10m. In the 2019/2020 season, maize, DKC8033 variety with potential yield of 8000kg ha<sup>-1</sup> was grown on all plots that previously grew legumes. These plots were split into two, one half maize was top dressed with a combination of 23kg N ha<sup>-1</sup> from urea fertilizer and 1000 kg ha<sup>-1</sup> of *mbeya* manure, and the other half received only the 23kg N ha<sup>-1</sup> from urea. The 23kg N ha<sup>-1</sup> from urea was applied to maize in order to complement the nitrogen (N) contributed by the legumes in the previous season. The maize response trials with or without *mbeya* manure and top dressed with 23kg N ha<sup>-1</sup> were replicated in 2020/2021 cropping seasons on other plots in the same EPA which had maize/legume rotations for the previous four cropping seasons. Details about the treatments implemented are presented in Table 1.

### *Mbeya* Manure

*Mbeya* manure was made by mixing ashes, chicken dung, urea fertilizer and maize bran. The proportion levels were as follows: 5 kg of ashes, 20kg chicken dung, 20kg of maize bran, 5liters of water, and 10 kg of urea fertilizer. These materials were mixed by slowly adding water until it changed color. The ingredients were fermented



for 21 days, this made carbon (C) in the form of simple sugar, volatile fatty acids and alcohol converted to CO<sub>2</sub> and methane, which resulted into less C (Organic matter), and made more N mineralized. Thereafter the manure was air dried and kept in a dry sack bag again ready for use. *Mbeya* is becoming more popular in Malawi. Government and non-government organizations train small holder farmers on how to make *mbeya* in most areas in Malawi. All resources except inorganic fertilizer used in making *mbeya* manure are found locally.

### Data analysis

The data on chlorophyll, plant height, total biomass and grain yield were subjected to the R statistical program and Genstat 18<sup>th</sup> edition computer package for analysis of Variance (ANOVA) (split-plot design). The means were separated by least significant differences (LSD) at 95% confidence interval ( $p < 0.05$ ). The R 4.3.1 statistical program was used in plotting graphs for the relationships between treatments (with or without *mbeya* manure) and grain yield for both responsive and non-responsive soils. Two criteria were used to determine the non-responsive farmer plots. The first criterion was the use of the average maize hybrid grain yield in Malawi under small scale farmers which is 2000 kg ha<sup>-1</sup>. All study units with grain yield of less than 2000 kg ha<sup>-1</sup> were considered as non-responsive units to legume cropping systems in rotation with maize. Using this criterion, a total of 13 farmer plots were identified as non-responsive. These plots represented 41% of total farmer plots on which the experiment was conducted. The second way was the use of the average grain yield of continuous maize with 23 kg N ha<sup>-1</sup> treatment which was 1745 kg ha<sup>-1</sup> in this study. All study units in which the legume cropping system yielded maize grain equal to or less than 1745 kg ha<sup>-1</sup> were also considered as non-responsive to legumes. Based on both criteria, the non-responsive units were separated from responsive units and their grain yield was analyzed by R 4.3.1.

## RESULTS AND DISCUSSION

### Soil characteristics

Table 2 shows baseline soil characteristics in the study sites. Soil pH averaged 5.3 and 5.1 in the top and sub-soils, respectively in Mkanakhoti EPA; and 4.9 and 4.7 in top and sub-soils, respectively in Kaluluma EPA. Soil organic matter (SOM) ranged from 1.1% to 1.8%. In Mkanakhoti EPA, 69% of plots had soil organic matter of less than critical value compared to 73% in Kaluluma EPA. Similarly, active soil carbon was highly variable between the farmer plots ranging from 23 mg/kg (very low) to 502 mg kg<sup>-1</sup> (slightly medium). Total soil nitrogen ranged from 0.004% to 0.84%, with a mean of 0.19% and 0.14% in top and sub-soils for both EPAs. In Mkanakhoti EPA, 33% of the experimental plots had total soil nitrogen of less than critical value (0.1%), and similarly 38% of farmer plots in Kaluluma EPA had total nitrogen below the critical value. The available phosphorus (P) was variable between farms ranging



from low (11.4 mg/kg) to high (101 mg/kg). Overall, 62% and 23 % of the plots in Mkanakhoti and Kaluluma, respectively, had available phosphorus less than the critical value. Overall, the baseline soil characterization showed that the soils are of poor quality to support optimum crop growth and development. Some of the soils in the study sites were acidic, with low organic matter, nitrogen, and phosphorous. According to Kahah *et al.* [14] and Sah *et al.* [15] maize requires deep soils with high organic matter to support growth and which store much more plant-available water.

### **Crop residue nitrogen inputs in 2018/19 and 2019/20 cropping seasons**

In both cropping seasons, on an area basis, the doubled-up legume system involving pigeon peas intercropped with either groundnut or soybean produced higher crop residue N yield as compared to sole cropped legumes (Table 3). Nitrogen is one of the major limiting nutrients on smallholder farms in Malawi. On area basis, the higher crop residue N inputs by the doubled-up legume cropping system compared to sole cropped legumes (Table 3) can be attributed to higher combined total biomass per area basis produced by the intercropped legumes (pigeon pea intercropped with either groundnut or soybean) and lower nitrogen harvest index than sole cropped legumes. These results on crop residue N inputs are similar to earlier studies by Chikowo *et al.* [16], who reported a range of 20% - 50% more biological nitrogen fixation inputs by doubled up legumes compared to sole cropped legumes [6, 17]. The N incorporated into the soil through crop residues can help to improve soil quality and productivity of the sequenced crop. However, in this study, where doubled up pigeonpea intercropped with soybean (PP+Soy) had higher estimated N inputs (84 kg N ha<sup>-1</sup>) compared to doubled up pigeonpea intercropped with groundnuts (Gn+PP) (77kg N ha<sup>-1</sup>) and other sole stands. This is justified by increased leaf biomass in (Soy+PP) treatment. According to Herridge *et al.* [18], soybean fixes more N than groundnut. However, in soybeans the high N harvest index (NHI) of up to 0.88 results in net export of N, hence justifies why higher estimated N in sole groundnut treatment compared to sole soybean treatment (Table 3).

### **Quality of mbeya manure used**

The *mbeya* manure was analyzed for some chemical characteristics over a period of six (6) weeks to determine if the duration of fermentation affects its quality. It was noted that the number of weeks for fermenting *mbeya* had no effect on the quality of *mbeya* in terms of total nitrogen, phosphorus, organic carbon and pH. The mean range of total nitrogen in *mbeya* manure was 7 to 7.6%, means of total phosphorus was the same (1.9%) during the fermentation period except when the materials were fermented for two weeks. Both organic carbon and pH were higher in the second week of fermentation than the other weeks. This was similar to the results by Katsura *et al.* [20] on the fermentation of poultry manure. The quality of *mbeya* manure was



not significantly affected by the number of fermentation weeks. This might be because the raw materials were the same for the whole duration of fermentation. During the fermentation of *mbeya* manure, the mineralization process increased the nitrate in the materials and resulted into formation of hydrogen ions during nitrification steps of mineralization. Some additional materials might be mineralized as the duration of the fermentation was increasing. This resulted in an increase in the total nitrogen and decrease in pH with a small magnitude. The organic carbon ranged from 23% to 19% during the fermentation period and was not significantly different but inversely proportional to the number of weeks for fermentation.

### **Effects of sole and doubled-up legume systems and *mbeya* manure on plant height and chlorophyll at 8 weeks after planting (WAP)**

The effects of legume systems and interaction of legume system and *mbeya* on chlorophyll content in maize at 8WAP were non-significant (Table 4). However, application of 1000 kg ha<sup>-1</sup> of *mbeya* manure to maize following the legume cropping systems increased chlorophyll content in maize (49.8 versus 30.4) (p=0.001). Similar results were observed on maize plant height which for all treatments responded positively to application of *mbeya* manure (p=0.001) (Table 4). The results of maize chlorophyll at 8WAP are similar to Mhango [6], who reported the non-significant difference between maize leaf chlorophyll following the sole groundnut or groundnut+pigeon pea doubled up system. The increased maize leaf chlorophyll in treatments with *mbeya* manure can be attributed to the quality of *mbeya* manure (Table 2) which provided extra nitrogen to the soil to support plant growth. Nitrogen is one of the key components of chlorophyll [21]. This is related to the study by Zingani *et al.* [22], who reported that nitrogen enhanced the chlorophyll content in maize. Additionally, *mbeya* manure applied had high phosphorous content 1.9% (Table 4), an essential nutrient element which is the component of adenosine triphosphate (ATP) that is involved in most biochemical processes in plants and enables them to extract nutrients from the soil and helps in N transportation and assimilation.

Similarly, application of 23kg N ha<sup>-1</sup> and 1000 kg ha<sup>-1</sup> *mbeya* manure in maize following legume cropping system increased maize plant height at 8 WAP compared to treatments without *mbeya* manure. This could be attributed to the quality of *mbeya* manure (Table 2) as discussed above. Compared to the sole cropped legume/maize rotations, on area basis, the doubled-up legume produced more leaf biomass and hence crop residue N inputs in the system (Table 5) and other soil quality benefits associated with high crop residue input hence more nutrient benefits to the subsequent maize. These results concur with Njira *et al.* [19] and Adane *et al.* [23] who found that the growth and yield components of maize significantly improved by

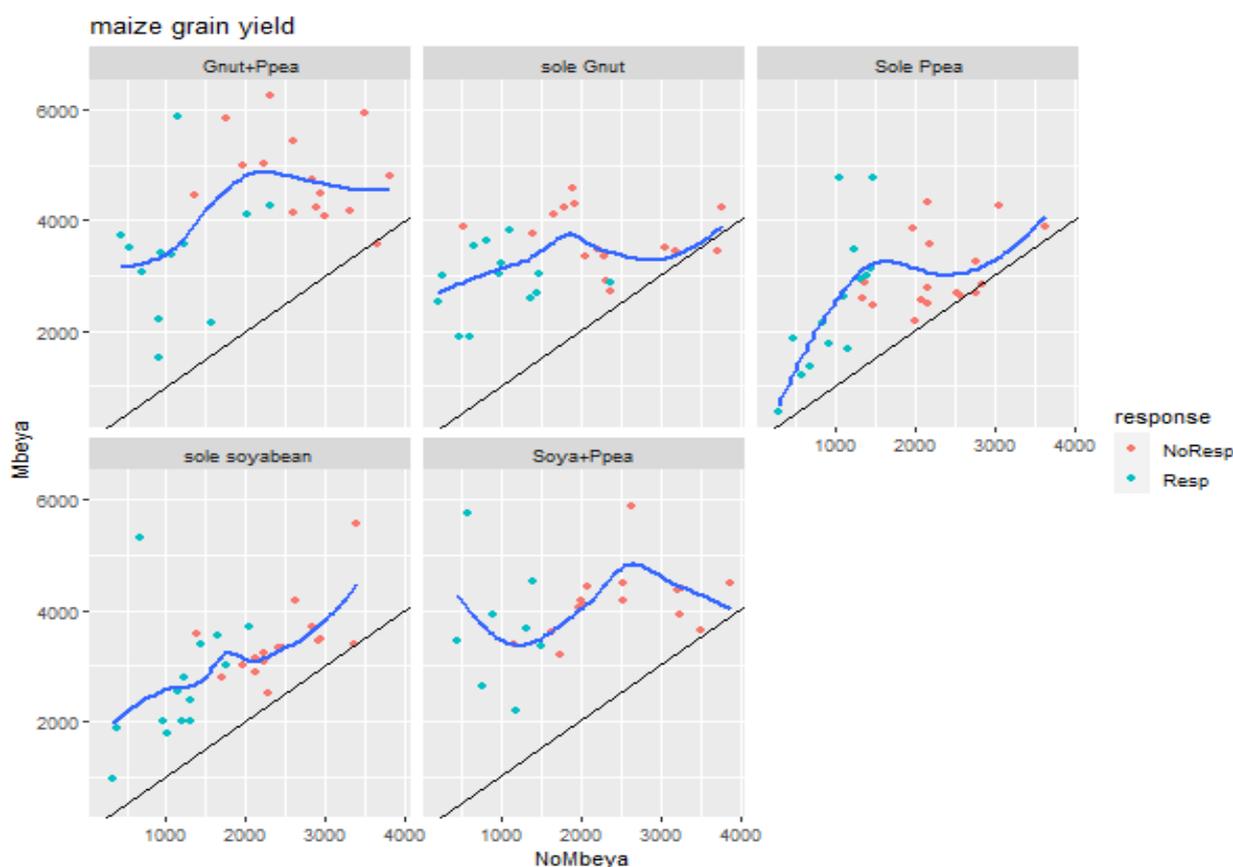


integrated soil fertility management involving use of synthetic fertilizer in combination with manure.

### **Effects of sole and double-up legume systems and *mbeya* manure on maize grain and total biomass yields for two cropping seasons (2019/2020 and 2020/21 seasons)**

In the 2019/2020 growing season, there was an interaction effect in terms of both maize grain and total biomass yields in response to legume cropping system (main factor) and *mbeya* manure (sub- factor) ( $p=0.001$ ) (Table 5). Application of *mbeya* manure to maize following the doubled-up legumes (both Soy+ PP and Gn +PP) increased maize grain and total biomass yields over maize following sole cropped legumes with or without *mbeya* manure and the doubled-up legume cropping system without *mbeya* manure. In general, maize following legume cropping systems and application of  $23 \text{ kg N ha}^{-1} + 1,000 \text{ kg ha}^{-1}$  *mbeya* manure had significantly higher grain yield and total biomass than the maize following legume cropping systems with application of  $23 \text{ kg N ha}^{-1}$  only. Among the treatments where *mbeya* manure was applied, maize following GN+PP produced the highest grain yield ( $4,175 \text{ kg ha}^{-1}$ ) followed by maize following soy+PP, and lastly, the sole cropped legumes/maize rotations (Table 5). In the 2020/21 season, interaction effects in terms of both grain yield and total biomass yield in response to legume cropping systems and *mbeya* manure were not significant. However, the application of *mbeya* manure to maize following legume cropping systems increased both maize grain yield ( $p=0.003$ ) and total biomass ( $p=0.021$ ) (Table 5). Figure 1 shows results for maize grain yield with *mbeya* manure against maize grain yield without *mbeya* under different legume cropping systems for 2019/2020 growing season. The black line is a 1:1 line, that is if *mbeya* had no effects, points would lie on this line, and if it had positive effects then points are above the line. The smooth blue curves show the average effect of *mbeya* as it varies by the level of grain yield in treatments without *mbeya* manure (X-axis). Using the 1:1 line, it clearly shows that *mbeya* manure had positive effects on maize grain yield following all the legume cropping systems (sole groundnut, sole soybean (Soy), sole pigeon pea, groundnut intercropped with pigeonpea, soybean intercropped with pigeon pea). This is because most of the points both for responsive soils and non-responsive soils are above the 1:1 line. The smooth (blue) curves through the points indicate that rotations with Gn+PP, Soy + PP, and sole groundnut were more responsive to application of *mbeya* manure on non-responsive soils and drop off on better soils (responsive farmer plots). In maize following sole soybean (Soy), the effect of *mbeya* manure is about the same for both responsive soils and non- responsive soils. The *mbeya* manure applied to maize following sole pigeonpea, did not have much influence on maize grain yield on non-responsive farmer plots.





**Figure 1: Maize grain yield in response to legume cropping system and *mbeya* manure on responsive and non-responsive soils**

Key: Gnut= groundnut, Ppea= pigeon pea, Soya= soybean

The high maize grain yield and total biomass in treatments with *mbeya* manure could be attributed to some properties which *mbeya* manure imported to the soil. The *mbeya* manure applied had high organic carbon which could hold soil nutrients for plant growth and development (Table 2). Additionally, the increased plant chlorophyll content of maize (Table 4) which is essential for photosynthesis might have contributed to this effect. The *mbeya* manure might also have increased soil pH. According to Sirisuntornlak *et al.* [24], maize performs poorly at extremely low and high soil pH and the optimum pH is 5.8. This was supported by Yan *et al.* [25], who reported that maize yield in response to nutrients such as phosphorus and agronomic efficiency to phosphorus increased with increasing soil pH. Additionally, low soil pH affects nutrients availability and maize plant growth. The baseline soil characteristic showed that most of the soils in the study sites were acidic, with pH of less than 5.5, hence *mbeya* might have had a positive effect on these soils. The results of 2020/2021 showed no interaction effects which might be attributed to the improved soil properties by legumes which were grown in these plots for a period of four seasons. The findings in this study are in-line with several authors. For example,

Salama *et al.* [26], reported that the integrated use of farmyard manure with mineral nitrogen in maize following faba beans or soybeans improved nitrogen use efficiency and maize yields compared to the application of mineral fertilizer only. The study by Ndengu *et al.* [27], complement that under smallholder farmer managed conditions, a combination of organic and inorganic fertilizer in maize-bean intercrop could enhance productivity and adaptability to climate change. Similarly, combining organic and mineral nitrogen fertilizer can have positive effects on productivity and agronomic efficiency of maize [28]. In other earlier studies conducted in Zambia and Tanzania by Mwila *et al.* [29] and Kinyua *et al.* [30] involving maize rotations with sole and doubled up legumes, doubled up legumes increased the subsequent maize grain and biomass yield. Overall, the findings from this study also shows potential of ISFM involving doubled up legumes and *mbeya* manure to improve maize productivity on highly degraded soils. The increase in maize yield following doubled up legumes can be attributed to higher amount of biologically fixed N per unit area compared to sole cropped legumes [17].

## CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

According to the results of this study, it can be concluded that integrated soil fertility management involving application of *mbeya* manure to maize following different legume systems enhanced plant growth, leaf chlorophyll content, plant biomass, the yield and yield components of maize under both responsive and non-responsive soils. Application of *mbeya* manure to maize following all the legume cropping systems improved maize grain yield and total biomass. The findings also show that in terms of maize yield, on non-responsive soils, treatments that had doubled up legumes (Gn+PP and Soy+PP) and groundnut were more responsive to *mbeya* manure than sole cropped soybean or / rotations. Therefore, an integration of *mbeya* manure and diversified legume cropping systems can be a good option for addressing soil fertility challenges in non-responsive soils. A study of similar design, including a control treatment with *mbeya* manure application but without legumes in-order to check the performance of *mbeya* fertilizer without legume is recommended.

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## Conflict of Interest

The authors declare no conflict of interest



**Table 1: List of treatments in 2018/19- 2019/20 and 2020/21 cropping seasons**

Treatments in 2018/19 and 2019/20	Treatment in 2019/20 and 2020/21
	Maize + 23kg N/ha + Mbeya manure
Sole soybean	Maize + 23kg N/ha
	Maize + 23kg N/ha + Mbeya manure
Sole pigeon pea	Maize + 23kg N/ha
	Maize + 23kg N/ha + Mbeya manure
Sole groundnut	Maize + 23kg N/ha
	Maize + 23kg N/ha + Mbeya manure
Groundnut + pigeon pea	Maize + 23kg N/ha
	Maize + 23kg N/ha + Mbeya manure
Soybean + Pigeon pea	Maize + 23kg N/ha

**Table 2: Baseline soil characteristics in Kaluluma and Mkanakhoti Extension Planning Areas**

Parameter	Soil depth (cm)	Critical Values	EPA	
			Mkanakhoti	Kaluluma
pH	0-15		5.3±0.05	4.9±0.05
	15-30		5.1±0.06	4.7±0.06
Total N (%)	0-15	0.1	0.19±0.02	0.19±0.01
	15-30		0.14±0.01	0.15±0.01
Available P. (ppm)	0-15	25	34.69±1.2	27.51±1.3
	15-30		23.20±0.9	23.61±1.7
SOM (%)	0-15	1.5	1.56±0.01	1.24±0.003
	15-30		1.5	1.2
Active Carbon (mg/kg)	0-15	400	169±4.9	216±6.1

SOM = Soil organic matter, P = phosphorus, N= Nitrogen, pH = power of hydrogen and ppm = parts per million



**Table 3: Crop residue nitrogen inputs (kg N ha<sup>-1</sup>) from sole and doubled up legumes over two cropping seasons**

Legume System	2018/19 season	2019/2020 season
Sole groundnut (Gn)	63	62
Sole soybean (soy)	50	43
Sole pigeonpea (PP)	43	43
Gn+PP	77	79
Soy+PP	82	84

Key: Gn=Groundnut, Soy=soybean, PP=Pigeon pea, (Gn+PP) = groundnut intercropped with pigeon pea; (Soy+PP) = soybean intercropped with pigeon pea

**Table 4: Maize chlorophyll readings and plant height at eight weeks after planting**

Legume system previous (Leg)	system season	Chlorophyll		Plant height (cm)	
		No mbeya	Mbeya	No mbeya	Mbeya
Sole groundnuts (GN)		30.1	41.5	37.5	54.5
Sole pigeonpea (PP)		31.0	43.7	40	58.3
Sole soybean (Soy)		31.1	59.3	40.1	56.6
GN + PP		30.8	43.4	39.4	58.7
Soy + PP		28.2	61.2	38.2	54.7
Mean		30.4A	49.8B	39.0A	56.6B
F. prob Legume		0.502		0.188	
Mbeya		0.001		0.001	
Legume x mbeya		0.400		0.815	
LSD (0.05)		19.79		4.3	
CV%		35		13.7	

Key: Means in a row followed by same uppercase letter are not different at  $p < 0.05$



**Table 5: Effects of legume cropping system and *mbeya* manure on maize grain yield (kg ha<sup>-1</sup>), and total biomass yield (kg ha<sup>-1</sup>) in 2019/2020 and 2020/2021 seasons**

Legume system previous season	2019/2020 cropping season				2020/2021 cropping season			
	Grain yield		Total biomass		Grain yield		Total biomass	
	<i>Mbeya</i>		<i>Mbeya</i>		<i>Mbeya</i>		<i>Mbeya</i>	
	No	Yes	No	Yes	No	Yes	No	Yes
Sole (GN)	1696aA	3300bB	6674aA	12235bB	3094a	4762b	9521a	11558b
Sole pp	1721aA	2809bA	6790aA	9437bA	3153a	4141b	8085a	10753b
Sole soy	1861aA	3062bAB	6769aA	11180bB	3028a	4007b	9131a	11308b
GN + PP	1919aA	4175bD	7448aA	13811bC	3443a	3910b	9811a	10455b
Soy + pp	2009aA	3835bC	6690aA	13994bC	3473a	4553b	9176a	11769b
F. prob (legume)	0.001		0.001		0.871		0.911	
( <i>Mbeya</i> )	0.001		0.001		0.003		0.021	
(Legume x <i>mbeya</i> )	0.001		0.001		0.851		0.927	
LSD (0.05)	304.9		2612.2		941.3		2401	
CV (%)	26.4		38.9		38.3		45.6	

Key: Gn=groundnut, Soy= soybean, pp = pigeon pea, and for each parameter, means in a row or column followed by the same lower- or upper-case letter are not different at p<0.05



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