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Productivity of pigeon pea and maize rotation system in Balaka District, Southern Malawi

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In Malawi, some parts of the country, such as Balaka District in Southern Malawi, are particularly prone to erratic rains with poor soil productivity. In the 2015/2016 rainy season some learning centres (LCs) focusing on pigeon-pea (*Cajanus cajan*) – maize (*Zea mays* L) rotations were established in four sections of Ulongwe Agriculture Extension Planning Area (EPA) in Balaka District to enhance soil fertility, nutrition and income diversification for increased resilience to production under erratic rain condition. Up to 132 plots of pigeon were established in 2005/2016 season. Of these 44 fields were sampled for yield, biomass, plant stand and 32 sites for soil data. In the second season of 2016/17, a maize fertilizer response trial with five rates of NPKS (0, 23:21:0+4S, 46:21:0+4S, 69:21:0+4S, and 92:21:0+4S) was super-imposed in the 44 fields, where farmers incorporated pigeon pea residues, a parallel study conducted in a nearby, adjacent field. In the first season, rainfall was low and erratic. Three dry spells (>10 non-rainy days) were recorded in two of four rain gauge stations, and two dry spells in one station. The soil test results showed low P, K and N status. Pigeon pea plant stand was low, with an average of 2.22 plants m⁻² compared to an expected 4.44 plants m⁻². Grain yields and stover weights were quite variable with a mean of 442 and 1698 kg/ha, respectively. In the second season maize yields grown in both old pigeon pea or continuous maize plots gave a linear response to fertilizer. The gains from pigeon rotation averaged 620, 308, 496 and -1072 for Chibwana Nsamala, Hindahinda, Mulambe and Chitseko sections respectively. The highest recorded yield was 4049 kg/ha from Hindahinda.

Key words: Pigeon peas, *Cajanus cajan*, green manures, maize response to nitrogen.

INTRODUCTION

Malawi is one of the countries that experience adverse effects of climate change. Environmental Affairs Department (EAD) (2002) noted that vulnerability of Malawi to climate change also mainly arises from socio-economic, demographic and climatic factors which include a slim economic base, limited agro-processing

facilities, over-reliance on rain-fed agriculture and fuel wood for energy.

Balaka District is one of the districts in Malawi that are vulnerable to climate shock, particularly drought (Government of Malawi, GoM, 2006). In Malawi climate change has been evident through inconsistent delays in

planting rains, frequent dry spells within the seasons and early termination of rains. This is one of the main contributors to low yields particularly amongst smallholder farmers. Between 2010/2011 and 2014/2015 average smallholder grain yields for maize and staple food ranged between 1.48 and 2.66 t/ha, compared to the potential yields of 5-7 t/ha (Ministry of Agriculture, Irrigation and Food Security, MoAIWD, 2012). International Maize and Wheat Improvement Centre (CIMMYT) (2013) noted that 40% of the area under maize in Sub-Saharan Africa experiences drought stress, which causes yield loss of 10 to 25%. Other constraints to production include poor soil fertility (Blackie and Mann, 2005; Kumwenda et al., 1997) and agronomic practices by farmers, and insect pests, parasitic weeds and diseases (Kabambe et al., 2008; Kabambe et al., 2014; Ministry of Agriculture, Irrigation and Water Development (MoAIWD, 2012). For example, phosphorus levels range from sufficient to low with widespread deficiencies in nitrogen and organic carbon ranging from 0.8 to 1.5% in Malawian smallholders fields (Snapp, 1998). To handle the poor soil fertility problem, the Government of Malawi initiated the Farm Input Subsidy Program (FISP), which has been making fertilizers and grain legume seeds available at very low prices (MoAIWD, 2015). Field application of manure is one of the approaches that increase plant water availability in the field, also referred to as *in-situ* water harvesting (Hatibu and Mahoo, 1999). In Malawi grain legume residues incorporation is widely encouraged as a green manure source. The main legume crops are groundnuts, pigeon peas, soybeans and cowpeas (MoIFS, 2012). Kumar Rao et al. (1987), Adu-Gyamfi et al. (2007) and Egbe et al. (2007) reported biological nitrogen fixation (BNF) of 20-118 kg/ha by pigeon pea. In Malawi, International Centre for Research in Semi-Arid Tropics (ICRISAT)/Ministry of Agriculture and Irrigation, MAI (2000) reported 300-500 kg/ha yield increases when maize was grown in rotation after pigeon peas residues were incorporated, while Ngwira et al. (2012) also reported increased yields in maize grown after legumes residues were incorporated compared to continuous maize.

In Malawi legume productivity by smallholder farmers is much lower than potential yields. Between 2010/2011 and 2014/2015 pigeon pea area ranged between 196,552 to 238,738 ha with average yields of 1119 to 1465 ha. The production area in 2014/2015 was 20.7% of total area under legumes (MoAIWD, 2015). The important factors for high productivity include well drained fertile soils, use of improved varieties and appropriate good agricultural practices (GAP) (MoAIWD, 2012). These

include early planting with first rains, effective weed control and timely harvesting. Use of clean, fungicide and insecticide treated seeds is important to achieve optimal plant densities (ICRISAT/MAI, 2000; MoAFS, 2012). Good early field crop establishment is useful for optimal extended capture of sunshine. Although legumes require phosphorus, there are no fertilizer recommendations in the production of pigeon peas in Malawi and many countries in tropical Africa (MoAFS, 2012; Singh et al., 2001).

The objective of this report was to measure the productivity of single cycle pigeon peas- maize rotation and determine the incremental benefits of incorporating legume residue of subsequent maize crop in drought-prone Balaka District. The process and results of the study were part of a broader objective to acquaint staff and farmers with broader understanding of managing and mitigating against climate variability.

MATERIALS AND METHODS

A two year study was conducted in Ulongwe Extension Planning Area (EPA) in Balaka District, southern Malawi to evaluate the productivity of pigeon peas and maize rotation system.

Site description and study design

The average 32- year rainfall for Balaka between 1979/1980 and 2010/2011 was reported as 809.8 with standard deviation of 229.3 mm (MoAIWD, 2012). In the first season (2015/2016) pigeon peas were planted in the rotation plots of 0.2 ha and 0.1 ha to establish one year cycle of legume-cereal rotations. Insecticide-treated basic seed of medium maturity 'mwai wathu alimi' was used. Up to 132 plots of pigeon pea were established. In each of the four sections there were 3 villages in which we had a lead farmer and 10 follower farmers making 33 farmers per section and a total of 132. Of these 44 fields were sampled for yield, biomass, plant stand and 32 sites for soils data.

In the second season of 2016/2017, five fertilizer treatments (Table 1) were randomly super-imposed in plots of the 44 fields of 2015/2016, where farmers incorporated pigeon pea residues. These fertilizer rates and packages represented choices available and recommended to farmers based on the fertility of their area (MoAIWD, 2012). A parallel trial was also conducted in which each of the farmers hosting the response curve treatments were also asked to plant the same fertilizer in a nearby, adjacent field where they had grown their own pure maize crop in 2015/2016. Planting dates were within the period, 15 November to 15 January 2016. The maize variety used was medium maturity hybrid DKC8033. To establish the baseline for the season, data were recorded from field samples taken from 3 rows 0.75 m apart x 4 m plots. Three such plots were taken from a farmer, and means were calculated for each farmer. Only the farmer means were used in all further data analyses and reporting.

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Table 1. Fertilizer treatments for 2016/2017 plots.

Treatment number	Treatment description
1	Maize without any fertilizer
2	Maize with 23:21:0+4S. Applied as a basal dressing only, from the compound 23:21:0+4S.
3	Maize with 46:21:0+4S. 23:21:0+4S applied as a basal the compound 23:21:0+4S and top dressing of 23 kg ha ⁻¹ N from and urea.
4	Maize and 69:21:0+4S. 23:21:0+4S applied as a basal the compound 23:21:0+4S and top dressing of 23 kg ha ⁻¹ N from and urea.
5	Maize and 92:21:0+4S. 23:21:0+4S applied as a basal the compound 23:21:0+4S and top dressing of 23 kg ha ⁻¹ N from and urea.

Data recording and analysis

Data were recorded on plant stand at harvest (plants m⁻²), stover weight (kg ha⁻²), pod number and grain yield. Stover and yield were taken after sun-drying for about two weeks, such that the moisture of the grain was considered the normal 10% storage level. For each crop and section the target was to harvest from all 3 lead farmers; there was hence a total of 15 farmers per section, and 45 farmers per EPA. Soil samples were collected from 0 to 20 cm depth from the same farmers and the pH, organic carbon %, organic matter %, nitrogen %, phosphorus %, potassium %, calcium %, magnesium %, zinc %, clay, silt and sand % of the soil were analyzed. The analyses were done using standard methods at Chitedze Research Stations Soil and Plant Analytical Laboratory. In the second season, moisture content of the maize grain was taken at harvest by a grain moisture meter and this was used to adjust yield to storage content of 12.5%. Yield data were subjected to analysis of variance. Analysis of variance was made separately for each pigeon pea – maize and continuous maize trial. Mean separations were made using the least significant difference, LSD_{0.05}. Other simple calculations were done to compare results, such as % change and value differences. Nitrogen use efficiency (NUE) was calculated for each of the treatments 2-5 as follows:-

NUE = Increment of nitrogen from unfertilized control/Increment of nitrogen from unfertilized control

Means of the variables for each section are presented. Regression and correlation analysis was done on pairs expected to have some relationships.

RESULTS

First season baseline rainfall, soils analyses and crop data

A summary of rainfall data monitored in four stations is shown in Table 2. Rainfall distribution was quite different between the stations. Dry spells of > 10 days were dominant. The rainfall recorded was lower than average rainfall of 840-900 mm for Mulambe and Chitseko sections, and 1,001 to 1,100 mm for Chibwana Nsamala

and Hindahinda sections (Juwawo, EPA in charge, personal communications, 2015). Results on soils and crop parameters, shown as means of sections, are given in Tables 3 and 4. Results on pigeon pea grain yield (kg/ha) and plant stand (plants/m²) are presented as summary means and standard deviation for each section in Table 4. There was wide variability in all parameters. For example, the expected plant stand at harvest was 4.44 plants m⁻²; however, recorded means ranged from 1.05 to 4.04 plants/m².

Second year maize yield results with and without pigeon pea residue incorporation

Maize yield results for maize after legume and continuous maize are shown in Tables 5 to 8. Significant treatment differences were recorded in all the sections. The pattern of response was linear for both pigeon pea to maize and maize to maize. The yield benefits of incorporating pigeon pea residue were highest in Chibwana Nsamala section (average 620 kg/ha, Table 5) followed by Mulambe (495 kg/ha, Table 8), and Hindahinda section (308 kg/ha) (Table 6). In Chitseko section (Table 7), yields without residue were higher than those with residue by an average of about 1.0 t/ha. Nitrogen use efficiency varied in magnitude for all the sections. NUEs were highest (up to over 30 kg grain/kg N) in Mulambe section.

DISCUSSION

Soil fertility status, rainfall and first year legume agronomic data

The results from year one (2015/2016) in which the legumes were established pointed to some clear potential production constraints in the area. The rainfall amounts

Table 2. Summary rainfall characteristics monitored at four stations in the EPA, 2015/2016.

Section	Village	Total rainfall (mm)	Rain days	Dry spells	Number of rainy pentades
Chibwana Msamala	Chibwana	407	13	3	6
Chibwana Msamala	Chombe	326	11	3	6
Chitseko	Kalembo 1	527	36	0	6
Mulambe	Namunde	461	16	2	6

Table 3. Means and standard deviation in brackets for soil chemical properties plots by section.

Section	pH water	% OC	% OM	% N	P (ug/g)	K (ug/g)	Ca (ug/g)	Mg (ug/g)	Zn (ug/g)
Chibwana N=10	6.32(0.45)	0.77(0.34)	1.33(0.60)	0.066(0.030)	0.466(0.262)	0.244(0.128)	5.96(3.72)	2.42(0.73)	8.40(2.44)
Hindahinda N=6	6.89(0.75)	1.67(0.51)	2.89(0.89)	0.144(0.04)	0.884(0.16)	0.631(0.334)	8.93(6.08)	4.13(3.28)	29.33(22.62)
Chitseko N=10	6.54(0.34)	1.31(0.32)	2.35(0.37)	0.11(0.18)	0.470(0.254)	0.370(0.169)	7.96(3.93)	2.42(1.37)	17.43(3.93)
Mulambe N=6	6.05(0.59)	0.654(0.27)	1.12(0.46)	0.056(0.023)	0.307(0.119)	0.306(0.218)	4.18(1.39)	2.67(0.91)	10.2(5.04)
G. Mean N=32	6.45(0.56)	1.13(0.47)	1.94(0.82)	0.97(0.04)	0.533(0.274)	0.378(0.238)	7.07(4.06)	2.96(1.76)	17.8(17.6)

Table 4. Means and standard deviations of agronomic variables and soil texture by section.

Section	Plants M2	Stover kg ha ⁻¹	Grain yield kg ha ⁻¹	Pod wt ha ⁻¹	Harvest index	% clay	% silt n=32	% sand n=32
Chibwana- Nsamala	2.044(0.378)	1274(724)	330(280)	794(679)	0.22(0.17)	13.6(3.7)	5.4(3.9)	80.9(3.7)
Hindahinda	2.452(0.67)	1820(752)	433(228)	1037(586)	0.20(0.07)	20.8(8.8)	10.7	68.5
Chitseko	1.970(0.76)	1343(708)	543(365)	1262(809)	0.32(0.13)	18.6(3.9)	7.0(4.8)	74.4(6.3)
Mulambe	2.299(0.52)	2684(886)	92(265)	248(701)	0.04(0.11)	10.2(5.0)	5.2(2.8)	56.0(3.2)
Grand mean n=44	2.18(0.52)	1698(886)	373(321)	889(760)	0.12(0.15)	17.4(5.3)	7.2(4.5)	73.4(8.2)

were low combined with dry spells (Table 2). It is likely these dry spells resulted in the poor crop pigeon pea establishments. MoAIWD (2012) noted that suitable rainfall for pigeon peas in dry areas is 700 mm per annum. Dry spells of > 10 days are considered serious enough to cause crop yield loss. The results on soil fertility point to soil fertility status as a problem for the area. Based on threshold values of Chilimba and Nkosi (2014), on average, the soils were very in low available P, low in K, very low - medium for N, very high in Zinc and almost neutral in pH. According to Chilimba and

Mkosi (2014), these soils would require 40 kg/ha phosphorus, 30-60 kg/ha potassium and 46-92 kg/ha nitrogen for optimal maize production. Snap et al. (1998) also reported similar low fertility from most soils in Malawi.

The pigeon pea yields were quite low compared to national average of 1465 kg/ha in 2014/2015. The main reason could be the dry spells which also occurred during flowering of the pigeon pea variety planted. Mhango et al. (2017) reported similar low yields in pigeon peas and attributed this to early season dry spells. The authors

Table 5. Maize grain yield (kg/ha) and nitrogen use efficiency (NUE, kg grain/kg N) with and without pigeon pea rotation in Chibwana Nsamala Section.

Fertilizer rate (kg/ha) (N:P:K:S)	With residues	NUE	Without residues	NUE	Value difference over no residues	% change over no residues
0	1717	-	1074	-	+643	60.0
23:21:0+4S	2052	14.5	1619	23.7	+433	26.7
46:21:0+4S	2433	15.5	1931	18.6	+502	50.2
69:21:0+4s	2830	16.1	2171	15.9	+659	30.3
92:21:0+4S	3224	16.4	2524	15.7	+700	27.7
Mean	2451		1831		+620	33.9
F Prob	0.031		<0.001			
LSD	991		671			
CV%	51.1		47			

Table 6. Maize grain yield (kg/ha) and nitrogen use efficiency (NUE, kg grain/kgN) with and without pigeon pea rotation in Hindahinda Section.

Fertilizer rate (kg/ha) (N:P:K:S)	With residues	NUE	Without residues	NUE (kg grain/kg N)	Value difference over no residues	% change over no residues
0	1137	-	1047	-	90	8.6
23:21:0+4S	1703	24.6	1438	14.3	265	18.4
46:21:0+4S	2066	20.2	1815	16.7	251	13.8
69:21:0+4s	2584	21.0	2122	15.6	462	21.8
92:21:0+4S	2822	18.3	2607	11.1	215	8.2
Mean	2062		1754		308	17.5
F Prob	<0.001		<0.001			
LSD	1023		497			
CV%	37.0		41.7			

Table 7. Maize grain yield (kg/ha) and nitrogen use efficiency (NUE, kg grain/kg N) with and without pigeon pea rotation in Chitseko Section.

Fertilizer rate (kg/ha) (N:P:K:S)	With residues	NUE	Without residues	NUE	Value difference over no residues	% change over no residues
0	1023		1811	-	-788	-43.5
23:21:0+4S	1572	23.9	1828	0.7	-256	-14.0
46:21:0+4S	1597	12.5	2610	17.3	-1013	-38.8
69:21:0+4s	1778	10.9	3135	19.2	-1357	-43.3
92:21:0+4S	2095	11.7	3613	19.6	-1518	-42.0
Mean	1613		2685		-1072	-39.9
F Prob	0.002		0.015			
LSD	521		1789			
CV%	42.4		48.6			

reported that plant density and inorganic P were main drivers for biological nitrogen fixation (BNF). Kumar Rao (1987) reported that pigeon pea can fix 69-100 kg N/ha. Myaka et al. (2006) and Egbe et al. (2007) reported that pigeon pea can have a net contribution of 2-60 kgN/ha

depending on the genotype and environmental factors. Most of the variation may be explained by variation between fields. Edmeadnes et al. (2000) reported that for fields varying in topography, texture and thickness of top soil, yields may vary ten-fold.

Table 8. Maize grain yield (kg/ha) and nitrogen use efficiency (NUE, kg grain/kg N) with and without pigeon pea rotation in Mulambe Section.

Fertilizer rate (kg/ha) (N:P:K:S)	With residues	NUE	Without residues	NUE	Value difference over no residues	% change over no residues
0	2129	-	1828	-	+301	+16.5
23:21:0+4S	2796	29.0	2581	32.7	+215	+8.3
46:21:0+4S	3416	28.0	2818	21.5	+598	+21.2
69:21:0+4s	3695	22.7	3333	21.8	+362	+10.9
92:21:0+4S	4049	20.9	3470	17.8	+579	+16.7
Mean	3213		2718		+495	+18.2
F Prob	<0.001		<0.001			
LSD	538		562			
CV%			21.6			

Maize yield response to nitrogen fertilizer application rate

The significant responses to N application in all sections in both legume and non-legume rotation crops are expected as the soils were low in nitrogen. Many soils in Malawi are low in nitrogen and require its application (Chilimba and Nkosi, 2014; MoAIWD, 2012; Kumwenda and Benson, 1998). The highest yields recorded of 2.5- 4 t/ha at 92 kg/ha N reflect are similar to upper yields reported from nation-wide trials by Kumwenda and Benson (1998). Therefore it is suggested that to raise yields beyond these levels, other constraints of the soil must be addressed, such as improving water holding capacity and soil organic matter of soil, identifying and applying some key missing nutrient. Yield benefits from the legume-maize rotation system were recorded in three of the four sections at varying levels. Rotational benefits from legume rotations have been widely reported in Malawi (ICRISAT/MAI, 2000; Mhango et al., 2017; Njira et al., 2017; Ngwira et al., 2012). The magnitude of benefits is at varying degrees, and could be due to many factors such as landscape position, tillage practices, adoption of *in-situ* rainwater harvesting technologies at farm level. However, the inverse results observed at Chitseko cannot be well explained.

Conclusion

The main lesson from these results is soil fertility in the study is low particularly for N and P. Due to the linear response observed, further studies to determine optimum rates are recommended and to determine the role of P and other nutrients in raising the upper yield ceilings of 2.5 to 3.0 t/ha recorded in the studies. Future crop management interventions should explore role of technologies such as *in-situ* rainwater harvesting techniques in counteracting the effects of dry spells at all

stages of crop growth for both legumes and maize

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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