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Productivity and profitability on groundnut (*Arachis hypogaea* L) and maize (*Zea mays* L) in a semi-arid area of southern Malawi

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In many parts of Malawi, including Balaka district in Southern Malawi, are prone to erratic rains with poor soil productivity and famer practices. A research and outreach project was initiated in October 2015 to establish learning centres (LCs) of groundnut: maize rotations as an entry point to diversify nutrition and income base of smallholder farmers, while building up on soil fertility for increased resilience to production under climatic variation. Some 132 plots of groundnut were established in 2015/2016 in four sections of Ulongwe Extension Planning Area (EPA) in Balaka district. Of these, 44 fields were sampled for yield, biomass, plant stand and soils data. In the second season of 2016/2017, a maize fertilizer response trial (five rates of $NP_2O_5K_2O$; 0, 23:21:0+4S, 46:21:0+4S, 69:21:0+4S, and 92:21:0+4S) was super-imposed in plots where farmers incorporated groundnut residues, in comparison with continuous maize from adjacent own field. In the first season, rainfall was below average and erratic, with 10-day dry spells recorded in two of four recording stations. The soils were generally poor, with test values below threshold for many variables including organic matter, nitrogen and phosphorus. Groundnut average yields and standard deviation were 754 (±186) kg/ha, respectively. Plant stands were poor, with up to 24% of the 46 LCs attaining ≤50% of targeted plant stand of 8.88 plants m^{-2}. Poor plant stand is suggested as a major contributor to low yields. Results from the 2016/2017 fertilizer response trials showed linear response of maize to fertilizer application. Yields ranged from an average of 1.47 t/ha without fertilizer application to 4.0 t/ha at 92:21:0+4S. It is concluded that the poor soil fertility, low field plant densities, and dry spells are the main causes of low yields. Gross margins were positive for groundnut yield of 1,000 kg/ha and fertilizer rates on maize of 46:23:0+4S and above.

Key words: Groundnut-maize rotation, nitrogen response, drought spells.

INTRODUCTION

Malawi is a country with an agriculture-based economy. In 2015, agriculture accounted for 30% of the gross domestic product (GDP) and 80% of the export earnings (Malawi Government, 2015). In 2013, agriculture employed 64.1% of the work force. The country has 2.4 M-ha of under cultivation, mostly by smallholder farmers who cultivate an average of 0.64 ha of land. Of the agriculture GDP, 70% is from smallholder farmers (Malawi Government, 2016). Agricultural production is almost fully dependent of rain-fed cultivation. There is one rainy season of 3 to 5 months per annum. Climate variability, particularly in the form of erratic rainfall is one of the major biophysical constraints to agricultural productivity (Challinor et al., 2007). Climate projections for Southern Africa to 2050 suggest an average increase in temperature by 2.12°C, a delay in the onset of the rains and more intense and widespread of droughts and floods (Cairns et al., 2013). 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%. The effects of drought increase the risk of crop failure which becomes a strong disincentive to farmers to invest in chemical fertilizers which are widely known to have positive influence on crop productivity. Other main constraints to crop production include poor and declining soil fertility (Zambezi et al., 1993; Kumwenda et al., 1997; ICRISAT/MAI, 2000; Blackie and Mann, 2005; MoAIFS 2005) and insects' pests, parasitic weeds and diseases (Kabambe et al., 2008; Kabambe et al., 2014; 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% on Malawian smallholders fields (Snapp, 1998). Thus, to overcome the widespread problems of soil fertility decline a more integrated soil fertility management (ISFM) approach is required. These include long term rehabilitation to build up soil fertility before crops respond to efficient use of applied nutrients (Tittonell et al., 2007). A major national intervention to redress the poor soil fertility problem has been the Farm Input Subsidy Program (FISP), which has been making fertilizers available at very low prices (GoM, 2012). The FISP also includes a component of legume seeds.

In Malawi, grain legumes are increasingly growing in importance. The national export strategy identified groundnuts to be among the four crops in priority area one for the export of oil seed products (GOM, 2013). As a green manure source, grain legumes are an important climate adaptation intervention as they help retain soil water (Tisdale et al., 1985). They contribute directly to household food security, and to the household cash income. Legume systems can positively contribute to the nitrogen economy of soils through biological nitrogen fixation, BNF (Snapp, 1998; Nyemba and Dakora, 2010). Recent studies in Malawi indicate that groundnut can fix between 21 and 124 kg/ha of N (Njira et al., 2012; Mhango, 2011). In Kenya, Ojiem et al. (2007) reported N fixation of 41 kg/ha under low rainfall and 124 kg/ha under high rainfall. Turner and Rao (2013) noted that while systems that apply N fertilizer have higher yields, they will be more impacted and have larger reductions in yields from climate change. However, Turner and Rao (2013) reported that even if impacted by periods of drought, these higher yields would still be higher than yields without fertilizer or with low inputs. In a study involving maize planting dates, cultivars and crop nutrient management under low and high rainfall environments in Zimbabwe, Rurinda et al. (2013) reported that nutrient management had an overriding effect on crop production, suggesting that nutrient management is the priority option for adaptation in rain-fed smallholder cropping systems.

Balaka is one of the districts in Malawi that are vulnerable to climate shock, particularly drought (GOM, 2006). The intensification of legumes in smallholder farming systems therefore has the benefits of diversifying food and income sources as well as the potential to increase soil N and increase water available. The studies in this report were therefore aimed at assessing the productivity of groundnut-maize rotations system in drought prone Balaka district, Southern Malawi.

MATERIALS AND METHODS

Study sites and design

A two-year legume-maize rotation study was conducted in Ulongwe Extension Planning Area (EPA) in Balaka district in Machinga Agricultural Development Division (ADD) in southern region of Malawi. Specifically, experimental sites were located in four sections of the EPA, namely Chibwana Nsamala, Hindahinda, Chitseko, and Mulambe. Being a field rotation study, field plots were established in 2015/2016 as the first season. In this season, pure stands of groundnuts were planted in fields of famers designated as lead (0.1 ha) or follower (0.05 ha) farmers and a designated density of 8.88 plants m^{-2}. The farmers were provided with basic seed and trained on good agricultural practices. The groundnut variety used was CG7 which has maturity period of 130 to 150 days and yield potential 2,500 kg/ha. Farmers were trained and supervised to ensure that recommended planting geometry of 75 cm between ridges, 15 cm between station, and 1 plant per station (MoAFS, 2012) were followed and that residues were incorporated. In the second season (2016/2017), five fertilizer treatments were imposed as shown in Table 1. These fertilizer rates and packages represented choices available and recommended to farmers based on the fertility of their area (MoAIFS, 2012). In addition, this was aimed at improving the teaching value of the studies. Plots had 4 rows and 6 m × 0.75 m apart (18 m^2), giving an expected density of 5.33 plants m^{-2}. Yield, plant count data were recorded from the two middle rows plot. All five treatments were randomly laid out in one field. The design was thus a randomized block with a farmer as a replicate.

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Table 1. Fertilizer treatments in the maize rotation plots, 2016/2017 plots.

Treatment No.	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 kgha^{-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 kgha^{-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 kgha^{-1} N from and urea.

Data collection and number of farmers involved

In the first year, 132 famers hosted groundnut plots, also designated as Learning Centres (LCs) in four sections. In each village, there was one lead famer and ten follower farmers. Of these 10 famers, all lead famers and 3 follower famers were sampled, for a targeted total of 48 farmers. From these famers, data were collected on soil, yield and stover to provide a basis for understanding the year two results. In year two, maize was grown as rotation crop on the same 48 farmers. This study design was randomized complete design with each farmer as replicate. Grain moisture content was recorded at harvest, and maize grain yields reported were adjusted to 12.5% storage moisture levels.

Data analysis

For the baseline year, data was summarized into means and standard deviations for each section and by legume crop type. For the year two data, analysis of variance was done on yields from legume maize plots and continuous maize separately using the structure sections×fertilizer level for each section.

Gross margin analysis computations

The computation for gross margin analysis involved determination of the difference between gross income from sales and production costs. The gross income was based on produce sales quoted at farm gate with negligible marketing cost. This is the actual situation in Malawi whereby small or big traders mount buying points in rural areas. The cost related to marketing is packaging which comprise a new sack for each 50 kg of harvest. The labour costs for groundnuts included land preparation, planting, weeding, stripping, shelling and grading while for maize these have included land preparation, ridging, planting, shelling, cleaning and packaging. These are basic components described by several authors (Dzanja, 2008; Ngulube et al., 2001; Takane, 2008). Dzanja (2008) estimated the total labour requirement to be 240 man-days for groundnut and 139 man-days for maize and these were used in the calculations. However, Ngulube et al. (2001) estimated the labour requirement for groundnut to be 637 man-days, while Takane (2008) estimated labour requirement for maize to be 176 man-days. Tables 2 and 3 show the total costs for groundnuts and maize at the five rates of fertilizer. The costs of inputs and labour use were those of the 2017/2018 cropping season in Malawi. At this time the exchange rate of the Malawi Kwacha to US $ was 1: 733 (June 2018 Newspapers). The labour was costed based on the minimum wage daily rate of MK 962,00 for the time of computation (June 2018). Calculations were made for different price and output scenarios. Breakeven yield was determined by dividing total costs of production by the price level.

RESULTS

First year soils, groundnut stover and grain yield baseline results

Results of rainfall from four measuring points are shown in Table 4. The total rainfall, ranging from 326 mm at Chombe village in Chibwana Msamala village in Chibwana Msaamala section of 527 mm at Kalembo 1 village in Chitseko was much less than normal rainfall. The long term annual rainfall for the EPA is 840 to 1000 mm. The rainfall was erratic, with up to 3 dry spells (periods with at least 10 days of no rain or trace rainfall) recorded in two sections, and 2 dry spells in another. Kalembo 1 village in Chitseko section had no dry spells as well as the highest rainfall.

Results of soil properties, stover and grain yield are shown in Tables 5 and 6. The results largely show poor soil fertility status, based on Chilimba and Mkosi (2014) thresholds. From the raw data (data not shown) all soil pH_w values were above 6.0 (neutral category) in all sections except Mulambe where values just below 6.0 were observed. All soils were very low in phosphorus and potassium with values <8.0 ug/g and <5.0 (very low categories). In terms of organic matter, soils were mostly in low (<2.1%) to medium (2.1 to 3.9%) category. For nitrogen, soils belonged to very low (<0.08%), medium (0.08 to 0.12%), low or medium (0.12 to 2.0) categories. All soils were very high in zinc (>3.0 ug/g). According to Chilimba and Mkosi (2014), these soils would require 40

Table 2. Variable costs (Malawi Kwacha, MK) used in the gross margin calculations for groundnuts (cf 1 US$=MK 733, June 2018).

Input of production	Groundnut yield level $kgha^{-1}$ and input/output value MK			
	300 $kgha^{-1}$	500 $kgha^{-1}$	1000 $kgha^{-1}$	1500 $kgha^{-1}$
80 kg seed	80,000	80,000	80,000	80,000
Labour 240 mandays at K962	250,120	250,120	250,120	250,120
Packaging bags	1200	2000	4000	6000
Total variable costs	331,320	332,120	334,120	336,120

Table 3. Variable costs (Malawi Kwacha) for the different fertilizer rates used in the gross margin calculations for maize (cf 1 US$=MK 733).

Input type	Fertilizer package $kgha^{-1}$ NPKS and inputs costs in MMK ha^{-1}				
	0	23:21:0:4	23:21:0:4	23:21:0:4	23:21:0:4
Seed 25 kg/ha	22,000	22,000	22,000	22,000	22,000
Labour at MK 962/man-day	265,512	265,512	265,512	265,512	265,512
Fertilizer	0	44,000	66,000	88,000	110,000
Total variable costs	287,512	331,512	353,512	375,512	375,512

Table 4. Summary rainfall characteristics monitored at four stations in the EPA, 2015/2016.

Section	Village	Total rainfall (mm)	Rain days	Dry spells	No. 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 5. Baseline yield, stover and soils texture from groundnut farmers fields in 2015/16. Figures in brackets are standard errors of means.

Section	Stover (kg ha^{-1})	Grain yield kg ha-1	% Clay	% Silt	% Sand
Chibwana-Nsamala	2887±1791	864±447	9.57±6.38	5.33±4.30	68.42±4.90
Hindahinda	2107±1011	1016±534	16.08±1.74	7.56±1.67	76.36±2.69
Chitseko	1865±1263	639±651	18.19±3.43	4.44±1.94	77.36±4.24
Mulambe	1222±1260	303±239	16.84±1.79	4.4±1.67	78.70±2.61

Table 6. Soil chemical characteristics from groundnut farmers' fields.

Section	pH water	% OM	% N	P (ug/g)	K (ug/g)	Ca (ug/g)	Zn (ug/g)
Chibwana-Nsamala	6.03±0.43	0.92± 0.36	0.046±0.018	0.45±0.24	0.307±0.276	9.57±6.38	5.33±4.30
Hindahinda	6.18±0.60	2.19±0.41	0.109±0.20	0.453±0.204	0.237±0.073	7.25±3.12	12.05±6.24
Chitseko	6.71±0.47	2.43±0.72	0.12±0.04	0.458±0.32	0.407±0.194	6.55±2.20	21.89±11.19
Mulambe	5.96±0.12	1.08±0.54	0.054±0.027	0.311±0.157	0.265±0.076	4.85±1.24	14.57±10.88

$kgha^{-1}$ of P_2O_5, 30 to 60 $kgha^{-1}$ of K_2O, and 46 to 92 $kgha^{-1}$ of N. However, sulphur, a potential important element, not determined. While all soils were low in fertility, the yields were quite variable. Average grain yield was the highest (1016 $kgha^{-1}$) in Hindahinda section and lowest (303 $kgha^{-1}$) in Mulambe. Of the individual plot grain yield (raw data not shown), the results showed that 27% of the 43 Learning Centres (LCs) studied obtained very low yields of >300 $kgha^{-1}$, while 24% obtained yields >1,000 $kgha^{-1}$ (Table 7). The target plant density in the study was

Table 7. Proportionate distribution of groundnuts yields from learning centres across four sections.

Yield range (kg/ha)	N	% of famers
≤300	12	27.3
≥300 - ≤500	7	16.3
≥500 - ≤1000	14	32.5
≥1000 - ≤1500	6	13.9
≥1500	5	11.6

Table 8. Association between actual plant densities and groundnut stover and grain yield across four sections.

Density category	Proportion of full stand (%)	N	Mean	Mean stover ($kgha^{-1}$)	Mean grain yield ($kgha^{-1}$)
≤0.44	≤25	10	3.67	1403	473
≥4.44 - <5.25	50-60	17	4.80	2142	743
≥5.25	≥60	19	5.92	2412	920

Table 9. Maize grain yield ($kgha^{-1}$) and nitrogen use efficiency (NUE, kg grain/kgN) with and without groundnut rotation in Chibwana Nsamala section.

Fertilizer rate $kgha^{-1}$ NPKS	Grain yield	NUE	Without residues	NUE	Value difference over no residues	%change over no residues
0	1356	-	1200	-	156	13.0
23:21:0+4S	1743	14.9	1634	18.9	109	6.7
46:21:0+4S	2048	15.0	1870	14.6	178	9.5
69:21:0+4s	2376	14.8	2141	13.6	235	11.0
92:21:0+4S	2636	13.9	2605	15.3	31	1.2
Mean	2078	-	1872	-	206	-
F Prob	<0.001	-	<0.001	-	-	-
LSD	731	-	54	-	-	-
CV%	27	-	36	-	-	-

8.88 plants m^{-2}. However, up to 22% of the 46 LCs had ≤50% of targeted plant stand of 8.88 plants m^{-2}, 37% achieved a plant density of between 50 and 60% of the desired plant stand suggesting poor establishment. This was most likely due to dry spells. There could be other soil factors too, particularly those linked to water holding capacity of soils. The reasons for poor stand were not studied. Table 8 shows the close association between grain and stover yield with the plant density categories.

Maize results in year two

Results on maize yield response to fertilizer rates in rotation with groundnuts or under continuous maize are shown in Tables 9 to 12. Significant treatment differences were detected in all the sections. The pattern of response was linear in all cases (Table 13). The incremental benefits due to groundnut rotation and residues incorporation varied according to the section. The benefits were highest in Chitseko section (range 233 to 732 kg/ha), followed by Chibwana Nsamala section (range 31 to 253). In Hindahinda, the results varied with some negative differences as well. There were no records obtained from Mulambe section.

Gross margin and break even yields

The gross margin for groundnuts were determined at four levels of production (300, 500, 100 and 1,500 kg/ha) and thrice price scenarios (MK 250, 350 and 500) to reflect the actual level obtained in the study. The results in Table 14, as expected, show that positive gross margins were only found and at yield levels of 1000 to 1,500 kg/ha and the K350 or K500 price scenarios. These yield levels were associated with plots that had high crop establishment (Table 8). Using a median total variable

Table 10. Maize grain yield (kgha^{-1}) and nitrogen use efficiency (NUE, kg grain/kgN) with and without groundnut rotation in Hinda-hinda section.

Fertilizer rate kg/ha NPKS	With residues	NUE	Without residues	NUE	Value difference over no residues	%change over no residues
0	1382	-	1468		-86	-5.9
23:21:0+4S	1954	24.9	2194	31.6	-240	-10.9
46:21:0+4S	2441	23.1	2405	204	36	+1.5
69:21:0+4s	2884	21.7	3008	22.3	-124	-4.1
92:21:0+4S	3514	23.2	3131	18.1	383	12.2
Mean	2526	-	2134	-	392	-
F Prob	<0.001	-	<0.001	-	-	-
LSD	702	-	492	-	-	-
CV%	35	-	24	-	-	-

Table 11. Maize grain yield (kgha^{-1}) and nitrogen use efficiency (NUE, kg grain/kgN) with and without groundnut rotation in Chitseko.

Fertilizer rate kg/ha NPKS	With residues	NUE	Without residues	NUE	Value difference over no residues	%change over no residues
0	1880	-	1362	-	+518	+27.8
23:21:0+4S	2610	31.7	2088	31.6	+522	+25.0
46:21:0+4S	3389	32.8	2657	28.1	+732	+27.5
69:21:0+4s	3811	30.0	3302	28.1	+509	+15.4
92:21:0+4S	4354	26.9	4121	30.0	+233	+5.6
Mean	3170	-	2706	-	+464	-
F Prob	<0.001	-	<0.001	-	-	-
LSD	881	-	882	-	-	-
CV%	25	-	41.9	-	-	-

Table 12. Maize grain yield (kgha-1) and nitrogen use efficiency (NUE, kg grain/kgN) with groundnut rotation in Mulambe.

Fertilizer rate kgha^{-1} NPKS	Yield	NUE
0	1654	-
23:21:0+4S	1941	12.5
46:21:0+4S	2391	10.7
69:21:0+4s	2546	19.4
92:21:0+4S	3044	15.1
Mean	2437	-
F Prob	<0.001	-
LSD	644	-
CV%	28	-

*Results from continuous maize plots were not available.

cost value of K334,120, the break even yield was 1336, 955 and 668 kg/ha for the MK250, 350 and 500 price scenario. For maize, positive gross margins were only possible at yields equal or above 2,500 which were associated with a rate of 46:23:0:4 or higher (Table 15). The break even yields were 1467, 1698, 1817, 1938, and 2058 for nil to 92:23:0:4 rate, respectively.

DISCUSSION

Baseline season results

The soil nutrient status of the soils, determined in 2015/2016 was low and below thresholds and yet groundnut grain and stover yields were quite variable.

Table 13. Linear regressions for nitrogen rate (kgha^{-1}) against maize yields (tha^{-1}) for groundnut-maize and maize-maize plots.

Section	Linear equation	R-Square
Groundnut after maize		
Chitseko	Y=0.039**x + 1.99	0.98
Hindahinda	Y=0.026**x +1.396	0.99
Mulambe	Y=0.0.014**x + 1.683	0.97
Chibwana	Y= 0.039**x 1.1396	0.99
Maize after maize		
Mulambe	Y=0.0293**x + 1.35	0.99
Hindahinda	Y=0.018**x + 1.63	0.93
Chibwana	Y=0.0144**x + 1.22	0.98

**Significant at P<0.01.

Table 14. Production costs, gross income and gross margins for groundnuts.

Input of production	Productivity level, kg/ha and input/output value MK			
	300 kg/ha	500 kg/ha	1000 kg/ha	1500 kg/ha
Total variable costs	331,320	332,120	334,120	336,120
Gross income at MK250 kg^{-1}	75,000	125,000	250,000	375,000
Gross income at K350 kg^{-1}	105,000	175,000	350,000	525,000
Gross income at K500 kg^{-1}	150,000	250,000	500,000	750,000
Gross margin at K250 kg^{-1}	-256,320	-207,120	-84,120	38,880
Gross margin at 350 kg^{-1}	-226,320	-157,120	15,880	188,880
Gross margin at K500 kg^{-1}	-181,320	-82,120	165,880	414,000

Table 15. Production costs, gross income and gross margins for maize four fertilizer rates (rounded up average yields).

Input type	Fertilizer package kg/ha NPKS and inputs costs in MMK/ha.				
	0	23:21:0:4	23:21:0:4	23:21:0:4	23:21:0:4
Yield average kg/ha	1500	2000	2500	3000	3500
Total variable costs including packaging MK	293,512	339,512	363,512	387,512	411,512
Gross income at MK100 kg^{-1}	150,000	200,000	250,000	300,000	350,000
Gross income at MK150 kg^{-1}	225,000	300,000	375,000	450,000	525,000
Gross income at MK200 kg^{-1}	300,000	400,000	500,000	600,000	700,000
Gross margin at MK100 kg^{-1}	-143,512	-139,512	-133,512	-87,512	-61,512
Gross margin at MK150 kg^{-1}	-271,012	-309,512	-326,512	-342,512	-359,012
Gross margin at MK200 kg^{-1}	6,488	60,488	136,488	212,488	288,488

This suggests that nutrient and non-nutrient factors were important, such as slope of land (not monitored), planting dates. There was significant regression relation between groundnut density and grain yield. Most of the fields recorded plant stand much lower than the expected stand of 8.88 plants m^{-2}. Thus, low establishment could be the main reason for low yields of groundnuts. The poor establishment is most likely due to dry spells experienced in the area. Being a large seeded crop, groundnut requires good soil moisture for establishment (MoAIWD, 2012). The result on relationship between plant stand and yield is in agreement with Mhango et al. (2017) who reported that plant density was one of the drivers of biological nitrogen fixation in groundnuts. Most of the variation may be explained by variation between fields. Edmeades et al. (2000) reported that for fields varying in topography, texture and thickness of top soil, yields may vary ten-fold.

For groundnuts, poor plant establishment was a key driver for yield. In this study, treated basic seed of groundnuts was provided and used. Hence, the reasons for poor establishment are likely to be the dry spells. Timing of planting relative to planting rains is important and this may be improved through provision of rainfall forecasting services and skills to determine moisture adequacy in soil. Possible ways to improve establishment include adoption of *in-situ* rain water harvesting practices such mulching, box ridges, and manure. It is recommended that all possible options to increase establishment should be tested and rolled out.

While there are no recommendations for nutrient application in groundnuts in Malawi, several studies have shown responses of P fertilizer application in groundnuts (Tarawali and Quee, 2014; Dakora, 1984). Mhango et al. (2017) reported that P was a key driver to BNF. It is recommended that further studies should be conducted to determine the role of P and other elements to increase yields of groundnuts in the area conducted. In a review, Chianu et al. (2011) highlighted several factors, including high soil temperatures, soil moisture stress, and P deficiency as important for groundnut yield.

Year two maize results

While responses to fertilizer were significantly different with or with residue incorporation, the yield levels of ≤4 tha^{-2} are still low as compared to potential of 5 to 10 t/ha for expected farmers' fields (MoAIWD, 2012). The low yields are expected as the soil analysis results showed that the soils were low in P and K. Higher rates would be required for higher yields (Chilimba and Mkosi, 2012). These soils would require 40 kg/ha phosphorus, 30 to 60 kg/ha of potassium and 46 to 92 kg/ha of nitrogen (Chilimba and Mkosi, 2012). The incremental benefits due to legume residue incorporation varied with section, with the highest benefits noted of 200 to 730 kg/ha recorded from Chitseko section. While the contribution legume residues to subsequent is well documented (Ngwira et al., 2012; Mwato et al., 1999; Mhango, 2011). Inconsistencies in maize response to legume rotations have previously been reported (Ngwira et al., 2012).

Gross margin analysis and breakeven yields

The gross margins determinations showed that profitability is higher at higher yield levels, which were associated with higher plant establishment in groundnuts and higher fertilizer rates in maize. Famers may reduce cost of groundnut seed by recycling their original certified seed. However, the value of insecticide or fungicide seed treatment with purchased seed may be lost. The best ways to increase yield remain good agricultural practices, such as timely planting and weeding, and proper plant density as discussed earlier.

RECOMMENDATIONS

The results have shown that general low yields in both groundnuts and maize are common and a constraint to profitability. For groundnuts, poor plant establishment was a key driver for yield. It is recommended that all possible options to increase establishment should be tested and rolled out. Further options to increase yields in groundnuts should be investigated, including application of P fertilizers. As the results have shown a linear response to fertilizer application in maize, an agronomic optimum could not be determined. While current fertilizer recommendation can be maintained, further studies on N response and their interaction with P should be added.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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