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Full Length Research Paper

Optimizing use of integrated soil fertility management options for profitable groundnut production in Uganda

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Soil fertility decline is a major constraint to groundnut production in Uganda. Whereas options exist to address this constraint, many have not been adopted by smallholder farmers. This study was designed to demonstrate the profitability of different integrated soil fertility management (ISFM) technologies in light of smallholder farmer conditions. On-farm experiments were set up in Mbale, Tororo and Bukedea districts of Uganda, with different inorganic fertilizer and farmyard manure (FYM) combinations and four groundnut varieties: Etesot, Red beauty, Serenut 2 and Serenut 3. Results revealed that under the ISFM options considered, Serenut 3 and Red beauty were the most profitable varieties. Serenut 3 and Red beauty posted positive gross margins for all treatments including the control. However, Serenut 2 posted negative gross margins across all treatments while Etesot had negative gross margins for the control and at 4.37 kg P ha^{-1}plus FYM. The optimum combination of fertilizer occurred at8.73 kg P ha^{-1} for red beauty and 4.37 kg P ha^{-1}+ 2 t FYM for Serenut 3, suggesting that blanket recommendations of ISFM interventions on groundnuts irrespective of variety, are not advisable owing to different varietal responses to ISFM interventions, different production costs and price of the groundnuts.

Keywords: Adoption, Dominance analysis, Profitability, Sensitivity.

INTRODUCTION

Declining soil fertility is a major constraint to agricultural productivity in East and Central Africa (ECA). According to Sanchez, P.A. (2002), the originally fertile lands that yielded 2-4 t ha^{-1} of cereal grains have turned infertile with grain yields of < 1 t ha^{-1} common. Unfortunately, adoption of best bet integrated soil fertility management (ISFM) technologies has remained minimal. This has been attributed to inadequate or lack of information, knowledge and skills in ISFM, limited technological options, lack of capital, unfavorable input and produce markets, unfavorable credit investment especially due to poor infrastructure, among others.

Despite the above limitations, the constraint of soil fertility decline needs to be addressed urgently if the ECA is to ensure increased food security and poverty reduction for the increasing population. According to Breman and Debrah (2003), if ECA is to rely on agriculture for economic development, an annual increase of 4 to 7% in food production is required. ISFM has been demonstrated as a

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strategy that can address the complexities and peculiarities of soil fertility management on smallholder farms (Bationo et al., 2003). The ISFM approach involves the combined use of organic and mineral resources, resilient germplasm, nutrient cycling and conservation (Vanlauwe et al., 2010). It is an approach that restores and maintains soil productivity. Use of ISFM improves conservation and synchronization of nutrient release with crop demand, leading to increased fertilizer use efficiency and higher yields. However, use of ISFM increases the production costs, and this must be justified with additional revenue from increased yields. For this reason investment in ISFM would make much more sense if the economic benefits can be demonstrated to smallholder farmers.

Groundnuts are an important crop widely grown in ECA. It provides food, feed, fertiliser, oil, fuel and income. It is useful in rotation through its ability to fix free nitrogen into the soil thereby improving soil fertility. Unfortunately, productivity is low, typically 0.85 t ha^{-1} (Kasenge, 2009) compared to the potential yield of 3 t ha^{-1}. The low productivity figures are partially attributed to pests and disease damage (e.g. rosette), low yielding varieties, and soil fertility (e.g. low P) limitations, among others. In order to increase yields to meet market demands, investment in ISFM is crucial. Veeramani and Subrahmaniyan (2011) cautioned that groundnut has a high nutrient requirement and the recently released high yielding groundnut varieties remove still more nutrients from the soil. Optimization of the mineral nutrition is therefore key to realizing higher groundnut yields. In most cases however, groundnut farmers use very low or no fertilizer, and sometimes only one or two nutrients. This results in mineral nutrient deficiencies due to inadequate and imbalanced use of nutrients and therefore low crop yields. In India for example, soil nutrient disorders contribute to a yield reduction of 30-70 per cent depending upon the soil types (Veeramani and Subrahmaniyan, 2011).

Phosphorus is the most important nutrient which affects the yield and quality of leguminous crops including groundnut (Patel et al., 1990). However, phosphorus is one of the major limiting plant nutrients in the tropical and sub-tropical soils (Nandwa 1998; Rao et al. 2004). It therefore follows that for sustainable groundnut production, phosphorus application is necessary. Organic materials improve soil physical and chemical properties, in turn increasing crop yields. The benefit of organic materials in increasing groundnut yields has been extensively reviewed (Veeramani and Subrahmaniyan, 2011). Whalen and Chang (2001) reported that application of P fertilizer in combination with farmyard manure (FYM) enhanced the effectiveness of P fertilizers resulting in higher groundnut yields. Reddy (1991) reported increased groundnut shelling percentage, 100 kernel weight, numbers of pods and pod yield per plant following application of FYM. The benefits of FYM addition in groundnut growth and yield has also been attributed to a range of factors including improvement in soil physical, microbial as well as nutrient availability such as N, P, K and Ca, and were more pronounced where combined with inorganic fertilisers (Deshmukh et al., 2005).

Although some farmers use farmyard manure (FYM), its availability has declined because of increase in cropping intensity and area, and other competitive uses of cow dung. However in some instances, organic resources such as FYM though available, are rarely used in farming. According to Bonabana-Wabbi et al. (2013) although most farmers in Eastern Uganda are aware of the value of FYM, many do not use it in farming. In addition, owing to the costs associated with fertilizers (both organic and inorganic), investment in fertilizer use must be economically viable in light of farmers' conditions. Moreover the smallholder farmers attempt to compare the incremental costs and incremental benefits associated with each new technology before they make a decision to use such technologies (CIMMYT 1988). For example, FYM contains only small amounts of major nutrients and its cost of transportation is often high. Furthermore, different groundnut varieties fetch different prices on the market, determined by consumers' preferences, cost of seed, yield differences and other attributes. It is therefore important to examine the importance of combining varietal and nutrient management combinations that are economically feasible for smallholder farmers.

Conducting economic evaluation of different ISFM options under farmer's own conditions has been found Paramount in informing recommendations for smallholder farmers and thus form the recommendation domain. Exiting ISFM technologies have not adequately been evaluated economically under farmers' conditions. The results of this study will therefore find relevance with a number of actors in this field. The objective of this study was to demonstrate the economic benefits associated with different ISFM options in groundnut production in eastern Uganda.

MATERIALS AND METHODS

Description of study sites

The study was conducted in Mbale, Tororo and Bukedea districts in Eastern Uganda. The study sub counties were Bungokho and Busiu in Mbale district, Kisoko in Tororo and Bukedeasub county in Bukedea district. Bungokho and Busiu sub counties stretch from 950 m asl to the slopes of Mt. Elgon, typically 1,400 m.asl and receive 1270 to 1400 mm of rainfall annually, distributed into one long rain season from March to October with a peak in April and a secondary peak in August. The dominant soils broadly consist of Lixisols characterized as strongly weathered soils with low levels of available nutrients and low nutrient reserves. Kisoko sub county in Tororo lies along Latitude: 0°39'0" and Longitude: 33°55'59.99", at1073 m.a.s.l. (http://ug.geoview.info/kisoko,231005) and receives an average of 1,490 mm, bi-modally distributed. Soils are sandy loams with pH 6.0. Bukedea sub county lies in Bukedea district, Latitude: 1.3475, Longitude: 34.044444, at 1040 m.a.s.l. It has a tropical climate with average an annual temperature of 23 °C. The average annual rainfall is 1230 mm, bi-modally distributed.

Experimental set up

Within each sub county, two farmers' groups comprising 30 members per group were selected. Four groundnut varieties were planted: the improved varieties (red beauty, serenut 2, serenut 3) and a local variety, Etesot. The improved groundnut varieties have higher oil contents and are resistant to Rosette disease (Laker-Ojok, 2005). The ISFM treatments included: 0, 4.37, 8.74, 13.1 kg Pha^{-1}, 2 t ha^{-1} farmyard manure (FYM), 4.37 kg P + 2 t ha^{-1} and 8.74 kg P + 2 t ha^{-1}FYM. Phosphate was applied as Minjingu rock phosphate (30% P_2O_5) and farmyard manure as well decomposed cow manure (pH 7.8, 5.3% OC and a C/N ratio of 12.7). The phosphate and manure were surface broadcast at time of planting.

The demonstrations took two forms: a mother demo which had 28 treatments (4 groundnut varieties and 7 ISFM treatments) and the baby demos where a farmer would choose any preferred treatments from the mother and establish them on his/her own farm (Snapp, 1999). During the growing season participatory evaluation of the demos was carried out through farmer to farmer visits and field days to obtain feedback from farmers as well as facilitating technology transfer. The experimental design was a randomized block design with a factorial arrangement of 4 groundnut varieties and 7 ISFM treatments, replicated four times (the sub counties).

Data collection and analysis

Data were collected on the weight of groundnut pods observed from a given area of the experimental plot. Samples of pods were collected and dried in the laboratory. The observed dry weights were expressed as yield on a hectare basis. The data were processed using Microsoft excel and statistically analyzed using Genstat package version 3.2. Significant differences between treatment means were determined at a 95% Confidence level and means separated using the standard error of difference (sed) procedure. Two means were declared as significantly different when the difference between them was greater than twice the sed value.

In order to conduct an economic analysis of the different inorganic and organic fertilizer management options in combination with the three groundnut varieties, partial budgeting marginal analysis and dominance analysis techniques were employed. Partial budgeting technique relies on the ability to isolate costs and benefits that vary with introduction of new technologies. It assumes that as technology users make the switch from the traditional practice or business as usual, they anticipate to make savings either in terms of reduced costs, increased benefits or reduced use of resources to attain the same or more output per unit area. Partial budgeting was employed to determine the various costs that vary with technologies and their corresponding benefits. The data were obtained from experimental records at the demonstration sites, farmers' own assessments, survey questionnaires and prevailing market prices and wages in the areas of the study. The gross field benefits (GFB) are estimated from the following equation:

$$GFB_i = (Y_i * P) - \sum_i TCV_i$$

……………………………………………………………………(1)

Where:

Y_i is the average yield of a particular groundnut variety per hectare, P_i is the farm gate-price per kilogram of a particular groundnut variety CV_i is the summation of the monetary values of all costs that vary per treatment.

Gross field benefits is what the farmer/technology user would gain if the output were turned into monetary units right at point of production without incurring other costs like marketing, transportation and storage costs. The idea is to consider all the positive attributes about the technology besides the crop yield, some of which may have an externality attribute. For instance the ability of groundnuts to fix nitrogen in the soils which benefits subsequent crops may also form the list of benefits. Likewise the costs considered in the same way include the foregone opportunity to use the resources elsewhere.

Marginal Analysis and Dominance Analysis:

$$MRR_{ij} = \frac{(NB_i - NB_j)}{TCV_i - TCV_j} * 100\%$$

……………………………………………………………………(2)

Where

MRR_{ij} is the Marginal Rate of Return between treatments i and j, NB_i is the net benefit of the $i^{th}$and j^{th} treatment and TCV_i is the total value of costs that vary for each of the treatments considered.

Dominance analysis was performed to identify treatments that had a higher cost and less benefits than a treatment of less costs. The analysis proceeds by arranging all treatments in order of increasing costs and examining the benefits. It is expected that treatments that cost more should also return more to the farmer than treatments of less costs. However, if a high-cost treatment

Table 1. Soil characteristics from Mbale, Tororo and Bukeda study sites

Site	pH	OC	N	P	Ca	Mg	K
		-------%--------		Ppm	------- meq/kg soil--------		
Mbale	6.18	1.61	0.16	9.15	7.35	3.70	0.26
Tororo	6.00	1.67	0.15	6.26	3.09	1.68	0.10
Bukedea	6.05	1.52	0.16	27.62	5.18	2.75	0.21
Critical values	5.2	1.74	0.20	45.0	1.65	0.14	0.14

benefits a farmer less than a lower cost treatment, that treatment is dominated and is not worthwhile to invest in. For this analysis a dominated treatment was identified as one for which the following was true:

$$D_i = \frac{(NB_{TCV_i} - NB_{TCV_{i-1}})}{TCV_i - TCV_{i-1}} < 0 \quad \text{..........(3)}$$

***Sensitivity Analysis*:**

$$\Delta TVC = \frac{P_i * \Delta Y_i}{(1+MRR_{ij})} P_i * \Delta Y \quad \text{..........(4)}$$

$$\Delta Y = \frac{\Delta TVC}{(1+MRR)} / P_i \quad \text{..........(5)}$$

Where:
ΔTCV is change in total costs that vary as a result of the technology P_i is the farm-gate price of a particular variety groundnut (market price or shadow price) ΔY is the change in groundnut yields per hectare as a result of the technology

Performing a sensitivity analysis either from the cost or yield side helps to determine the range of prices over which the technologies remain economically appealing. If there is a change in critical input or output prices, the technology users may wish to know whether they remain afloat and also if less than the expected yield is obtained, whether they will breakeven.

RESULTS AND DISCUSSION

Soil characteristics in the study areas

Table 1 presents the soil characteristics of Mbale, Tororo and Bukedea study sites in eastern Uganda. From these results it can be seen that the soils in the study sites were slightly acid, pH 6.18, 6.00 and 6.05 for Mbale, Tororo and Bukedea respectively. The Mehlich III extractable phosphorus was lowest in the Tororo study site followed by Mbale. However, values for the three study sites were below the critical value of 45 ppm, suggesting that P was low in all sites (Table 1). With the low P levels, it would make sense to use phosphate fertilizer on these soils. The Ca and Mg values were above critical values in all three sites; Tororo had low K levels.

Effect phosphate fertilizer and manure application to groundnut yields

Groundnut yields were significantly (P<0.05) affected by differences in varieties planted as well as fertilizer rates applied. The mean yield (shelled) was significantly (P<0.05) lower for Serenut 2 compared to other varieties (911 vs 1589 vs 1741 vs 1518 kg ha^{-1}, for Serenut 2, Red beauty, Serenut 3 and Etesot, respectively).Application of ISFM packages (Minjingu rock phosphate and FYM) significantly (P<0.05) increased groundnut yields. Average groundnut yield was 855 kg $ha^{-1}$for the control but this was increased to 1390 kg ha^{-1} on application of 4.37 kg Pha^{-1} (equivalent to 50 kg SSP ha^{-1}). Further increments in the P rate beyond the 8.74kg Pha^{-1}did not significantly increase groundnut yields.

On the other hand, application of farmyard manure (2 t ha^{-1}) significantly (P<0.05) increased the mean groundnut yield from 855 to 1573 kg ha^{-1} (Figure 1). However, combining manure and Minjingu rock phosphate did not significantly increase yields over what was attained from the application of either farmyard manure or the phosphate alone. With this result, it would appear that there was no significant yield difference between the phosphate, FYM and phosphate plus FYM treatments applied in this study. However, an economic analysis of the different management options disaggregated by variety revealed some interesting results as presented below.

Results of the partial budget and Marginal analysis

In Table 2, the results of the partial budget analysis technique are presented across the different groundnut

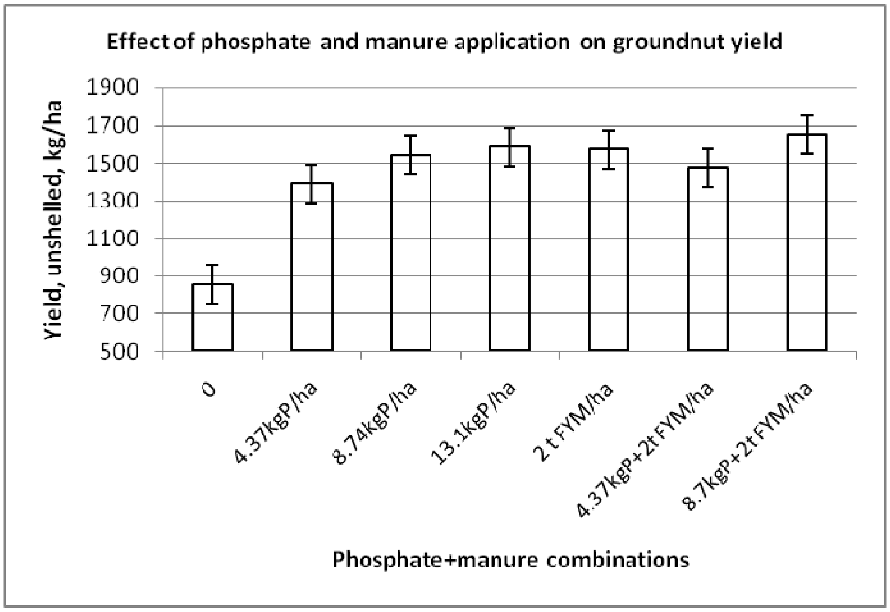

Figure 1. Effect of applying phosphate and farmyard manure on groundnut yield

Table 2. Partial budgets of ISFM technologies in Eastern Uganda

		Phosphorus (kg P ha^{-1}) and farmyard manure (FYM) combinations						
Variety		0	4.37	8.73	13.1	FYM	4.37 + FYM	8.73 + FYM
Etesot	yield, kg (shelled)	477.6	777.6	990	1268	1162	813	888
	revenue	419	683	869	1,113	1,020	714	779
	cost	480	619	694	769	935	721	860
	margin	-61	64	175	344	85	-8	-80
Red beauty	yield, kg (shelled)	638	1,177	1,546	1,107	981	1,163	1,173
	revenue	793	1,461	1,919	1,374	1,218	1,444	1,456
	cost	651	790	865	940	1,106	892	1,031
	margin	141	671	1,054	434	111	552	425
Serenut 2	yield, kg (shelled)	386.4	604	510	595	461	561	709
	revenue	485	757	640	746	579	704	890
	cost	627	765	841	916	1,082	868	1,007
	margin	-142	-8	-201	-170	-503	-164	-117
Serenut 3	yield, kg (shelled)	749	1,105	1,030	1,166	1,753	1,637	1,093
	revenue	940	1,387	1,294	1,463	2,201	2,056	1,373
	cost	692	830	906	981	1,147	933	1,071
	margin	249	557	388	482	1,054	1,123	301

Note: Price (US $/kg) of groundnut varieties at harvest: Etesot=0.878; Red beauty=1.242; Serenut 2=1.255; Serenut 3=1.256.

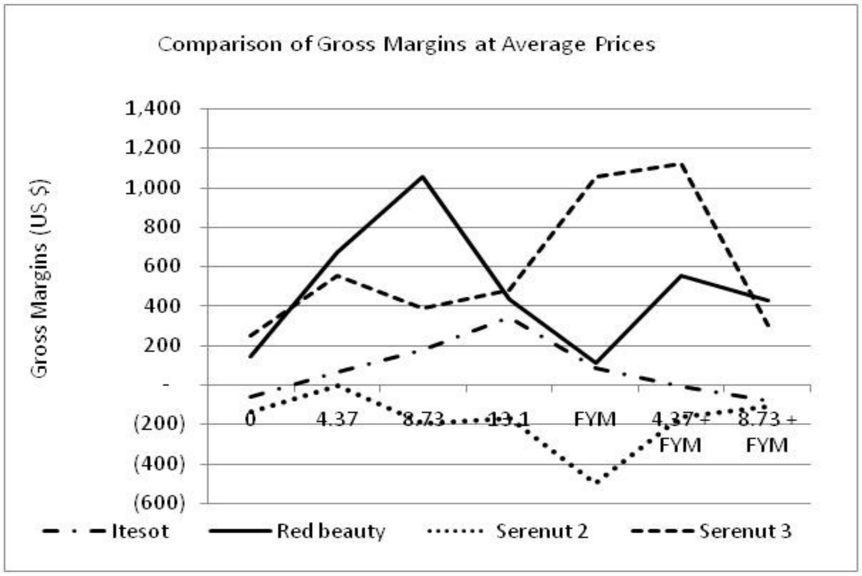

Figure 2. Gross Margins for ISFM technologies on groundnuts at Average Prices

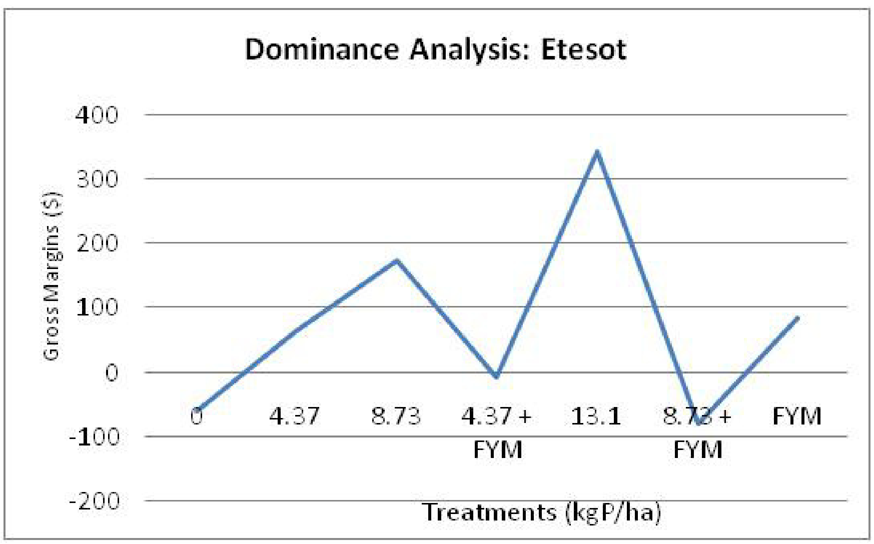

Figure 3A. Dominance analysis for Etesot groundnut variety with different fertilizer rates at average prices.

varieties and fertilizer combinations in Mbale, Tororo and Bukedea study sites. The yields and prices used in the computations are averages pooled across the three areas. The prices used reflect the average prices pooled across time. Considering the costs that vary per treatment, the gross margins are reported. Across all varietal treatments, the highest cost treatments were those that involved FYM (whether used singly or in combination with the inorganic fertilizer). It can be seen that all the fertilizer combinations for Serenut 2 and the control posted negative gross margins at the price of UGX 3137 per kg (Table 2). Similarly, Etesot groundnut variety posted negative gross margin for the control and the two fertilizer treatments that combined inorganic fertilizer and manures. The best performing varieties were Serenut 3 and Red Beauty which resulted in positive gross margins for all treatments including the control.

Figure 2presents the comparison of gross margins in USD. Profitability (as measured by gross margins) varied across treatments. Positive margins were attained at all fertilizer combinations applied on Serenut 3 and Red Beauty (including the control). Gross margins for Red Beauty were highest for lower than 13.1 kg ha^{-1} while for Serenut3 profitability was highest at higher P levels. This

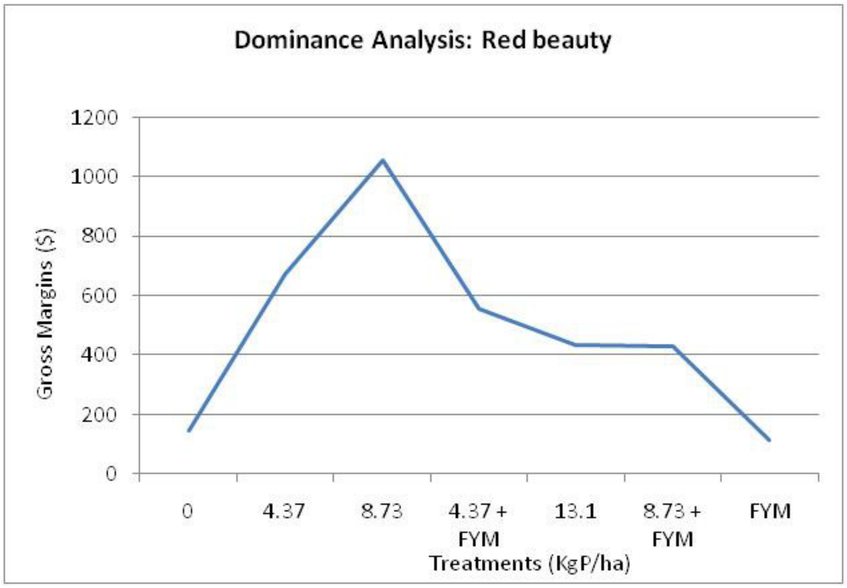

Figure 3A. Dominance analysis for Red beauty groundnut variety with different fertilizer rates at average prices.

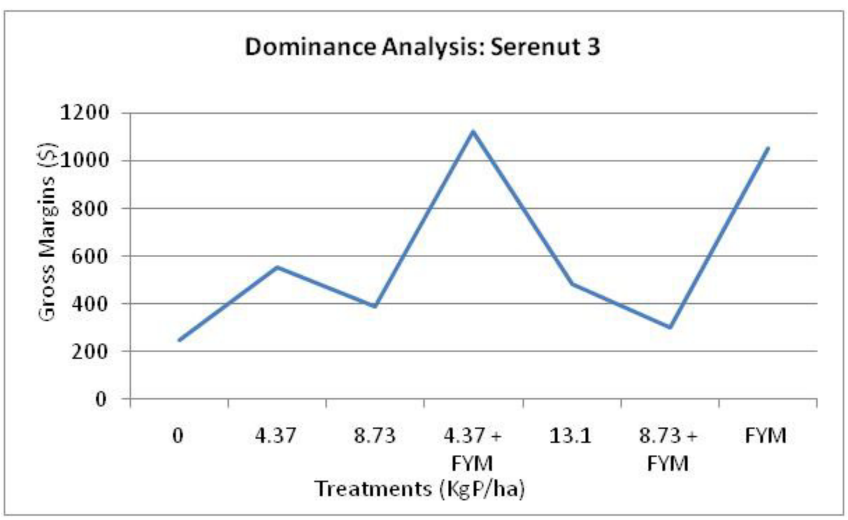

Figure 3. Dominance analysis for Serenut 3 groundnut variety with different fertilizer rates at average prices.

result implies that for the two varieties, different fertilizer regimes are appropriate if the farmer is to optimize benefits from the ISFM technologies. Serenut 2 performed poorly especially when only FYM and no inorganic fertilizer is applied. The local variety Etesot had positive margins at fertilizer levels between 4.37 and 13.1 kg ha^{-1}.

Figure 3 shows the results of the dominance analysis for the two best performing varieties (Serenut 3 and Red beauty) compared with the traditional farmers' variety Etesot. From the graphs in Figure 3, the optimum fertilizer combinations at the prevailing input and out prices varied by variety. For Etesot, the non-dominated treatment was the one corresponding to 13.1 kg P ha^{-1} while for Red Beauty the non-dominated treatment was the 8.74 kg ha^{-1}. With regard to Serenut 3, the non-dominated treatment was 4.37+FYM. All the other treatments had lower benefits than a treatment of lower costs, or lower benefits than the non-dominated treatment. In general, across all varieties, all treatments with only FYM were dominated owing to high costs of the FYM and less than commensurate yields. Investment in dominated treatments is not justifiable and is not worthwhile for the farmer.

It is important to note that the result of the dominance analysis coincide with those of the marginal analysis. The added advantage of the dominance analysis is to identify the treatments whose higher costs are justifiable. In the results here, higher costs (of US $ 769) for treatment 13.1 kg P ha^{-1}on Etesot are justifiable by higher gross margins (of US $ 344) compared to say, treatment FYM whose costs are higher but with lower gross margins.

Results of the Sensitivity analysis

In smallholder production, prices of inputs and outputs are key drivers of profitability and may determine the thresholds of farmers that break-even. In order to test the plausibility and range of output prices over which our results remain economically viable, we re-analyzed our data with average prices immediately after harvest, average prices at one month after harvest and average prices at the time of planting the next season groundnut crops. The results revealed a similar trend as that portrayed using prices overall average prices, with Serenut 3 and Red beauty posting the highest gross margins across treatments.

CONCLUSION AND IMPLICATIONS

The results of the analyses show that ISFM interventions increase groundnut yields. Yields from fertilizer applications (whether inorganic or organic farm yard manure) to soil resulted in higher yields compared to the control, irrespective of the variety. This result points to the soil improvement properties of ISFM technologies in groundnuts and the resultant improvement in yields. It is important to note however that for each variety, further increases in fertilizer beyond threshold, results into less and less yield increments suggesting that there is a level beyond which further addition of fertilizer is not warranted. Economic assessment of the treatments showed that gross margins arising from varying fertilizer levels varied by variety owing to differences in costs, prices of products and yields from each treatment. With the exception of Serenut 3, all other varieties showed low gross margins for all treatments involving only FYM which might suggest that for these varieties, combinations of both organic and inorganic soil amendments are not necessary for higher gross margins owing to the cost of FYM and the less than commensurate rise in yield accruing from FYM. Results showed that for a local variety Etesot, the optimal fertilizer level that resulted in higher margins was the 13.1 kgPha^{-1} while for Red beauty, the optimal level was 8.74 kgPha^{-1} and for Serenut3, optimality was attained at 4.73 kg P ha^{-1} combined with 2 t ha^{-1} farmyard manure. These results arise because different varieties respond differently to ISFM interventions (fertilizer levels), have different costs of inputs (seed and fertilizer related costs) and price of the groundnuts.

This study has demonstrated that use of ISFM approaches (low levels of phosphate and farmyard manure) can considerably increase groundnut yields, with associated economic benefits. However, these inputs must be applied to the right variety to justify the investment in fertilisers. In the current study, red beauty grown with 8.73 kg P ha^{-1} was and serenut 3 grown with 4.37 kg P ha^{-1} combined with 2 t FYM ha^{-1} were the most profitable management options compared to other varieties.

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REFERENCES

Bationo A, Mokwunye U, Vlek PLG, Koala S, Shapiro BI (2003). Soil fertility management for sustainable land use in the West African Sudano-Sahelian zone. In: Soil Fertility Management in Africa: A regional Perspective. Academy Science Publisher and Tropical Soil Biology and Fertility.pp 253-292.

Bonabana-Wabbi J, Kirinya J, Kasenge V, Semalulu O, Ariho A, Mugonola M, Mogaka

Breman H, Debrah SK (2003). Improving African food security. SAIS Review vol. XXIII (Winter-Spring) No. 1, 153-170.

CIMMYT (1988). *From Agronomic Data to farmer recommendations An Economics training manual*. Revised edition Mexico: CIMMYT [Centro Internacional deMejoramiento de Maíz y Trigo (International Maize and Wheat Improvement Center)].

Deshmukh KK, Khatik SK, Dubey DP (2005). Effect of Integrated use of inorganic, organic and bio fertilizers on production, Nutrient availability of plateau and Satpura hills. J. Soils Crops. 15: 21-25.

H (2013). Scaling up Integrated Soil Fertility Management (ISFM) for Improved Livelihoods: Combined Baseline and Capacity Building Needs Assessment Uganda Baseline Report. ASARECA (Unpubl) Report.

Kasenge V, Semalulu O, Gumisiriza C (2009). Promoting Natural Resource Management through Effective Governance and Farmer-market linkages. Baseline survey report: Banana and Groundnut participatory value chains survey in Bududa and Mbale districts of Uganda. ASARECA (Unpubl.) Report.

Laker-Ojok, 2005.

Nandwa SM (1998). Overview of soil fertility in Tropical Africa. A lecture presented at the International Training Programme on development of fertilizer recommendations for optimum crop production. Holiday Inn Hotel, Nairobi, Kenya. April 20–25 1998.

Patel MP, Shelke VB, Shelke DK (1990). Response of groundnut to weed management and phosphate in pre-monsoon season. J. Maharashtra Agric. Univ, 15: 313-316.

Rao IM, Barrios E, Amezquita E, Friesen DK, Thomas R, Oberson A, Singh BR (2004). Soil phosphorus dynamics, acquisition and cycling in crop-pasture-fallow systems in low fertility Tropical soils: a review from Latin America. In: Delve R.J. and Probert M.E. (eds), Modelling Nutrient Management in Tropical Cropping Systems. ACIAR proceedings. pp. 126–134

Reddy SK, Srirama Murthy VMM, Shantaram MV (1992). Nitrogen, phosphrous and sulphur nutrition of groundnut (Arachis hypogaea L.) grown in alfisols. J. Oilseeds Res. 9(2): 189 – 195.

Snapp SS (1999). Mother and baby trials: A novel trial design being tried out in Malawi. Target Newsletter of the Southern African Soil Fertility Network, Vol. 17, no. 8.

Vanlauwe B, Chianu J, Giller KE, Merckx R, Mokwunye U, Pypers P, Shepherd K, Smaling E, Woomer PL, Sanginga N (2010). Integrated soil fertility management: operational definition and consequences for implementation and dissemination. 19th World Congress of Soil Science, Soil Solutions for a Changing World 1 – 6 August 2010, Brisbane, Australia.Published on DVD.

Veeramani P, Subrahmaniyan K (2011). International Journal of Engineering Science and Technology (IJEST) ISSN: 0975-5462 Vol. 3 No. 11 November 2011 8138.

Whalen JK, Chang C (2001). Phosphorus accumulation in cultivated soils from long-term annual applications of cattle feedlot manure. J. Environ. Qual. 30: 229-237.