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The adoption potential of biomass transfer and improved fallow practices in eastern Uganda: Determining profitable and feasible options from a farmer perspective

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Abstract

Many advocate for the use of organic and inorganic fertilizers to restore declining soil fertility. However, most farmers cannot afford to purchase inorganic fertilizers because they are beyond the budgets of most households. Limited access to both credit and markets prevent their use. Organic fertilizers are also a difficult option as small farm size and insufficient labour availability often hinder their production. To estimate the adoption potential of integrated fertilizer options by smallholder farmers, on-farm maize productivity trials were conducted with 10 farmers. The study contrasted twelve treatments of different levels of inorganic fertilizer with improved fallow (IF) species (*Mucuna pruriens* and *Canavalia eniformis)* and the biomass transfer (BT) species (*Tithionia diversifolia)*. Analysis identified optimal combinations of organic and inorganic soil improvement options at varied price levels of inputs and outputs to assess the sensitivity of outputs to price fluctuations. Profitability and associated required investments (capital, labour, and land) of the options within a farm context (labour and capital availability) were assessed using a linear programming model. Tororo district in eastern Uganda served as a case study where farms have on average 2 ha of land in 2 enterprise scenarios. All IF and BT treatments are profitable and were sensitive to labour and maize price fluctuations. The optimal treatment for the farmers scenario was found to be the farmer's practice for the tithonia treatment and 1.8 t ha^{-1} of tithonia on 1.9 ha of land, whilst for the proposed practice scenario, with all labour activities costed and a high value of maize used, the optimal mix was found to be the integrated use of tithonia (0.9 tha^{-1}) and 30 kg inorganic nitrogen on 0.42 ha and N-P-K inorganic fertilizer on 0.495 ha of land. The optimal net benefit in each case could be US $780.1 and US $713.5 respectively. The result showed that a soil improvement practice could be incorporated into the farmer's field using the farmers' usual farming practice with a higher net benefit and if using the integrate approach, the land size should be reduced for economical reasons.

Key words: Cover crops, improved fallow, legumes, sensitivity analyses, soil fertility

Introduction

Uganda has one of the highest rates of nutrient depletion in Africa. Average figures are estimated in excess of 60kg ha^{-1} Nitrogen (N), Phosphorus (P), and Potassium (K), NPK each year (Henao and Baanante, 1999), implying that sustainability of crop yields is maintained at low levels of soil productivity. Although 90% of the people in Uganda are engaged in agriculture, yields in comparison to potential yields are low (Ministry of Agriculture, Animal Industries and Fisheries, (MAAIF), 1999). The World Bank (1997) estimated that in 1990, the productivity gap averaged 3.8 t ha^{-1} of maize between crop yields at experimental stations and farmers' fields. This gap is attributed to nutrient mining from crop harvests and other losses over time.The integrated nutrient approach has been advocated by many as the most sustainable method for soil fertility improvement (Graene and Casee, 1998). While mineral fertilizers are an important soil fertility management input, organic inputs also serve as compliments in fertility management strategies. Soil organic matter increases the efficiency of mineral fertilizer use and improves soil structure. In sub Saharan Africa (SSA), however, mineral fertilizers have become too expensive for most resource-poor smallholder farmers to purchase.

Structural adjustment policies brought on by budgetary cutbacks have led to the removal of inorganic fertilizer subsidies (FAO, 2001b). In Uganda, the Plan for Modernisation of Agriculture (PMA), has laid emphasis on technology-based agriculture, to incorporate external inputs (e.g. inorganic fertilizers) into smallholder farming systems, with input distribution entrusted to the private sector. The government has also withdrawn farm input subsidization (Ministry of Agriculture, Animal Industries and Fisheries, (MAAIF) & Ministry of Planning and Economic Development (MFPED), 2000). Despite this, the external inorganic input use has remained minimal. The annual inorganic fertilizer application rates are less than a kilogram of nutrients per hectare. As a result, many farms suffer from negative nutrient imbalances (Kaizzi *et al.*, 2002).

The use of improved fallow (IF) and biomass transfer (BT) has been reported in Eastern Africa (Rommelse, 2000; Sanchez, 1999; Franzel, 1999; Fischler and Wortmann, 1999). These technologies were introduced into farming systems in Tororo District, eastern Uganda (Waata *et al.*, 2002, Nyende and Delve, 2004). The shrubs and trees introduced into farming systems included *Mucuna pruriens, Canavalia ensiformis, Tithonia diversifolia, Sesbania sesban, Crotalaria ochroleuca, Calliandra calothrysus, Dolichos lablab, and Tephrosia vogelli* species. These species were used as BT and IF or green manure (GM) technologies. The species of interest in this paper are subset of the above species, which have shown the most promise: Mucuna, Canavalia and Tithonia.

Numerous merits and demerits have been identified with these technologies. Hindrances to the adoption of the IF and BT technologies have been centred around increased demands on production factors such as land, labour and capital (Fischler and Wortmann, 1999; Pali *et al.,* 2003). Indeed, the average land size in these farms in Tororo is 2 ha (DSOER, 1997), and the agricultural production is mostly subsistence. These smallholder farmers are characterised by low level of operation, complete reliance on household resources and the retention of household produce for food security purposes (Adejobi *et al*., 2004). Farmers are therefore faced with the challenge of how best to utilize their scarce resources.

The labour resources associated with IF, BT and GM technologies are additional to those required by regular farm and non-farm activities (Pali, 2003). In Honduras, some farmers reported reductions in post harvest labour by 15- 20% and fewer weeds (Neill and Lee, 2001, Buckles and Triomphie, 1999), while labour for uprooting many of these shrubs was seen as intensive (Fischler and Wortmann, 1999; Pali, 2003; Nyende and Delve, 2004). *Tithonia diverifolia*, is grown as a hedgerow and used as BT. It's reported labour intensiveness is derived from cutting, sorting and transporting the biomass to the field. In the management of IF, it has been established that the age of the fallow, the wood mass are positively related to the labour requirement for cutting the fallow Rommelse, (2000). The farmer response to these additional labour demands is to hire labour for peak labour demand periods, which include the incorporation of the BT or IF, land preparation and harvesting practices. Farmers use family labour for the off peak seasonal labour, however, they do not attach a value to this labour to give it an opportunity cost. Therefore this study attempts to ascertain which nutrient management method farmers would use given their resource endowment, if they were to have the practice of costing major labour requirements in the enterprise to a more informed and enterprise oriented production method. Although most economic studies impute labour value by estimating its shadow price, farmers do not value their family labour, and therefore, its opportunity cost was valued at zero. Economic studies have also attached the same labour value for each agricultural activity for each person when conducting economic analyses of agro forestry technologies (Rommelse, 2000). However this may not be the case with peak labour demand periods such as harvesting (Pali *et al.*, 2004) having a shadow price of labour than non-peak periods. The use of market driven values of labour when these farmers are not fully integrated into the market using market-derived values is likely to be inadequate (White *et al.*, 2004).

This study explores scenarios where the opportunity cost of family labour is valued at zero for non-peak labour during the cropping season and the scenario where all labour is valued at the same rate and peak product prices are taken advantage of. It is based on the assumption that non-peak labour has no shadow price (farmers practice) and that farmers sell their agricultural produce and consequently keep track of market prices of their produce. The objective of this study is to determine the optimal soil management treatment for two scenarios where all labour is valued and major labour activities are valued.

Methodology

Site description and experimental design

Tororo district in eastern Uganda has a land area of 2,336 km^2 and is located 33°45′ - 34°15′ E 0°30′ - 1°00′ N. Altitude ranges between 1,100 m and 2,350 m.a.s.l. The main economic activity in Tororo is farming of cereal crops such as sorghum, maize, and cassava. Besides that sale of surplus harvests, farmers earn incomes from cash crops such as cotton. Soils comprise sandy clays and loam with low organic carbon and low soil fertility.

Farmer managed on-farm trials were conducted on ten fields in the Osukulu and Kisoko Sub-counties of Tororo District. An unfertilised maize crop was grown for one season before the start of the experiment, in order to equalize the soil fertility conditions. The beneficial maize crop planted following the fallow season and after incorporation of the biomass transfer organic material was thinned to one seed per hole after two weeks (53, 200 plants ha^{-1}). Longe 1 maize hybrid variety was planted at a spacing of 0.75m by 0.25m. A randomised complete block design was used with each of the ten farms acting as replicates. The maize was harvested at the end of each season. In the improved fallow experiment, no amendments were made to the soil at the time of legume planting. Plant spacing for Mucuna was 0.75 x 0.6m and Canavalia 0.75 x 0.3m. The fallow cover crops were cut at the beginning of the next season, allowed to wilt for five days and incorporated into the soil at the rate of 33.3 labour days per hectare (LD ha^{-1}), at the rates of 50% and 100% of the aboveground biomass. Leaves and soft twigs of Tithonia were collected from local hedgerows, spread evenly over the plots and incorporated the same day. A summary of the experimental treatments is given in Table 1 and a more detailed aspect of the IF and BT species experiment has been reported (TSBF, 2002).

The Linear programming problem

Enterprise budgets for each trial were estimated with two different scenarios (CIMMYT, 1988) to derive the gross margins (Tables 2- 4). The results of the partial budget were subjected to Linear Programming (LP) analysis to determine the optimal soil management options (SMOs) for each of the different scenarios (Table 5). LP allows the unique optimal solution with the consideration of alternatives (Reklaitis *et al.*, 1983; Bernard and Nix, 1993).

Objective function

The problem was to maximise the discounted net benefits subject to constraints.
The linear programming problem is stated in equation 1.
Maximize:

$$GM = \sum_{k=1}^{12} \sum_{t=1}^{n} GM_i \, \mathrm{T_i} \qquad 1$$

Where:
GM_i = gross margin of the i^{th} SMO in United States Dollars (US $) $hectare^{-1}$,
t = 1…n, Where t is the season, and n is the second season for BT Soil Improvement Practice (SIP) and third season for the IF SIP; k = 1….12 experimental treatments
T_i = the i^{th} SMO or i^{th} treatment with different resource levels.

Resource constraints

Resources are the labour and capital inputs used in the experiments. The average prevailing exchange rate (1 United States Dollar = 1,500 Uganda Shillings), labour and maize output prices for the year 2000 were used. The average peak and slump maize prices of US$ 0.2 kg^{-1} and US$ 0.1 kg^{-1} respectively, were used in this study. The labour wage rate was valued at US$ 1.0, (including the cost of US$ 0.33 lunch allowance).

Two scenarios were studied. Fully costed labour with peak output selling price, which depicted the farmers' opportunity cost of family labour and took advantage of the high maize prices. It assumes that the farmers will store produce whilst monitoring output prices and sell during peak price periods. The second scenario laid much emphasis on family labour for the weeding of maize activity. Only major labour activities such as land preparation, ploughing, incorporation of shrubs, fertilizer application, and harvesting were valued at the cost of hired labour in the village. This scenario depicted the practice that is on going in the area of study.

The constraints in the raw data were US $375.2 depicting the farmers' annual income. A maximum total of 310 Labour days ha^{-1} two $season^{-1}$ was used based on the average prevailing labour utilisation in the area (for associated activities of cereal crops). These values were derived from a farmer survey conducted following experimental trials.

Equation 2 and 3 show the inequalities where the farmers' gross income p.a. (US $), labour (workdays), were used as constraints. All treatments were experimented on 5x5m plots and financial results were extrapolated to unit hectare basis.

Subject to:

$$\sum_{k=1}^{6} b_C T_i \leq I \qquad 2$$

$$\sum_{k=1}^{6} b_L T_i \leq L \qquad 3$$

Where:
$\hat{a}_{Ci}$, $\hat{a}_{Li}$ are coefficients for input costs (in US $), and the labour (in man-days $hectare^{-1}$) respectively used for the i^{th} SMO, T,
I = Farmers' gross annual income in US $
L = Average available labour used for maize production in Tororo in workdays $hectare^{-1}$,
k = 1….12, where k is the Experimental treatments
The models also include traditional non-negativity constraints.

Table 1. Treatments using Tithonia biomass and improved fallows (Mucuna and Canavalia) as transfer sources of nitrogen

Units (kg ha^{-1})	Organic Nitrogen	Inorganic Nitrogen	Phosphorus	Potassium	Yield season 1	Yield season 2
			BIOMASS EXPERIMENTS			
1.82 t ha^{-1} Tithonia P+K	59.2	-	80	60	3,410	3,410
N+P+K	-	60	80	60	3,390	3,390
P+K (Control)	-	-	80	60	2,710	2,710
0.91 tha^{-1} Tithonia	29.6	30	-	-	3,780	3,780
Farmers practice* (Control)	-	-	-	-	2,210	2,210
1.82 t ha^{-1}Tithonia	59.2	-	-	-	2,860	2,860
			FALLOW EXPERIMENTS			
P +K (Control)	-	-	80	60	2,300	2,800
Farmer's practice* (Control)	-	-	-	-	1,700	2,200
100% Mucuna	80	-	80	60	3,700	3,700
50% Mucuna	2	-	80	60	3,500	3,300
100% Canavalia	120	-	80	60	3,500	3,300
50% Canavalia	38	-	80	60	3,000	3,300

· This shows that the there was nothing added to the farmer's soil to simulate the farmer's situation.

Table 2. The Profitability analysis the farmers practice scenario

Improved Fallow (IF) practice

Treatment	Average yield (kg ha^{-1})	Labour utilization (workdays)	Returns to labour (US$)	Total Variable Costs	Net Benefits
Natural Fallow	1,950	91.2	3.44	163.8	195.0
Natural Fallow P + K	2,550	106.8	3.02	268.3	201.5
50% Canavalia	3,150	106.7	3.64	319.6	262.2
50% Mucuna	3,400	114.7	3.80	326.2	304.1
100% Canavalia	**3,400**	**131.3**	**3.32**	**340.0**	**290.3^{D}**
100% Mucuna	3,700	134.5	3.65	347.5	337.5

Treatment	**Costs**	**NB**	**Change in TVC**	**Change in NB**	**MRR**	**% MRR**
Farmers Practice	163.8	195.0	-	-	-	-
Control PK	268.3	201.5	104.5	6.6	0.1	6.3
50% Canavalia	319.6	262.2	51.3	60.7	1.2	118.3
50% Mucuna	326.2	304.1	6.6	41.9	6.3	633.3
100% Mucuna	347.5	337.5	21.2	33.4	1.6	157.6

Biomass Transfer (BT) practice

Dominance Analysis

Treatment	Average yield (kg ha^{-1})	Labour utilization (workdays)	Returns to labour (US$)	Total Variable Costs	Net Benefits
Farmers Practice	2,800	160.9	3.30	179.6	397.3
1.8 t ha^{-1}Tithonia	3,210	171.4	3.59	221.2	438.4
0.9 t ha^{-1} Tithonia + N	3,640	208.6	3.30	238.4	514.2
Farmers Practice P+ K	**2,940**	**171.4**	**2.68**	**282.0**	**324.8^{D}**
Tithonia P&K	**3,420**	**220.2**	**2.52**	**325.3**	**376.8^{D}**
N+P+K	**4,100**	**208.6**	**3.13**	**345.4**	**397.3^{D}**

The Marginal Rate of Return Analysis

Treatment	Total Variable Costs	Net Benefits	Change in TVC	Change in NB	MRR	% MRR
Farmers practice	179.6	397.3	-	-	-	-
1.8 t ha^{-1}Tithonia	221.2	438.4	41.6	41.2	0.991	99.1
0.9 t ha^{-1} Tithonia +N	238.4	514.2	17.2	75.8	4.394	439.4

Table 3. The Linear program in detached coefficient form (Raw data) for the Farmers practice

Variable	Soil Management Option	Objective function (US $)	Costs (US $)	Total Labour (Labour days)
A	Farmers Practice	397.3	179.6	160.9
B	1.8 t ha^{-1} Tithonia	438.4	221.6	171.4
C	0.9 t ha^{-1} Tithonia + N	514.2	238.4	208.6
D	Natural fallow	195.0	163.8	91.2
E	Natural Fallow P + K	201.5	268.3	106.8
F	50% Canavalia	262.2	319.6	106.7
G	50% Mucuna	304.1	326.2	114.7
H	100% Mucuna	337.5	347.5	134.5
Resource Availability (Farmers Resource Constraints)			375.2	310

Table 4. The profitability analysis the proposed practice scenario

Improved Fallow (IF) practice

Dominance Analysis

Treatment	Average yield (kg ha^{-1})	Labour utilization (workdays)	Returns to labour (US$)	Total Variable Costs	Net Benefits
Natural Fallow	1,950	269.4	1.82	243.5	290.6
Natural Fallow P+K	2,550	288.6	1.91	348.0	351.4
50% Canavalia	3,150	299.95	2.24	404.7	461.4
50% Mucuna	3,400	307.95	2.42	411.3	527.0
100% Canavalia	**3,400**	**324.6**	**2.29**	**425.1**	**513.2**^{D}
100% Mucuna	3,700	334.2	2.47	432.5	587.1

The Marginal Rate of Return Analysis

Treatment	Costs	Net Benefits	Change in TVC	Change in NB	MRR	% MRR
Natural fallow	243.5	290.6	-	-	-	-
Natural fallow P+K	348.0	351.4	104.5	60.8	0.6	58.2
50% Canavalia	404.7	461.4	56.70	110.0	1.9	194.0
50% Mucuna	411.3	527.0	6.60	65.6	9.9	993.9
100% Mucuna	432.5	587.1	21.20	60.1	2.8	283.5

Biomass Transfer (BT) practice

Dominance Analysis

Treatment	Average yield (kg ha^{-1})	Labour utilization (workdays)	Returns to labour (US$)	Total Variable Costs	Net Benefits
Control FP	2,800	290.44	2.80	292.7	566.0
Tithonia 0.91 t ha^{-1}	3,210	336.86	2.78	334.3	647.6
Tithonia +N	3,640	338.13	3.13	351.5	768.8
Control P&K	**2,940**	**300.92**	**2.51**	**395.1**	**508.1**^{D}
Tithonia P&K	**3,420**	**349.74**	**2.57**	**438.4**	**606.8**^{D}
N+P+K	4,100	338.04	3.14	458.5	786.3

The Marginal Rate of Return Analysis

Treatment	Costs	Net Benefits	Change in TVC	Change in NB	MRR	% MRR
Control FP	292.7	566.0	-	-	-	-
Tithonia 0.91t ha^{-1}	334.3	647.6	41.6	81.6	1.962	196.2
Tithonia +N	351.5	768.8	17.2	121.2	7.047	704.7
N+P+K	458.5	786.3	107.0	17.5	0.164	16.4

Table 5. The Linear program in detached coefficient form (Raw data) for the proposed practice

Variable	Soil Management Option	Objective function (US $)	Costs (US $)	Total Labour (Labour days)
A	Farmers Practice	566.0	292.7	290.4
B	1.8 t ha^{-1} Tithonia	647.6	334.3	336.8
C	0.9 t ha^{-1} Tithonia + N	768.8	351.5	338.2
D	N + P + K	786.3	458.5	338.1
E	Farmers Practice	290.6	243.5	263.4
F	Farmers Practice P + K	351.4	348.0	288.6
G	50% Canavalia	461.4	404.7	353.5
H	50% Mucuna	527.0	411.3	361.5
I	100% Mucuna	587.1	432.5	334.2
Resource Availability (Farmers Resource Constraints)			375.2	310

Table 6. The optimal solution to the fallow and biomass linear programme for farmers practice

Variable	Soil Management Option	Land (Ha)	Investment Costs (US $)	Labour (Labour days)
A	Farmers Practice	0.900	161.64	144.81
B	1.8 t ha^{-1} Tithonia	0.963	213.40	165.0
C	0.9 t ha^{-1} Tithonia + N	0	0	0
D	Natural fallow	0	0	0
E	Natural fallow P + K	0	0	0
F	50% Canavalia	0	0	0
G	50% Mucuna	0	0	0
H	100% Mucuna	0	0	0
Resource utilization under optimal solution		1.863	375.04	309.81
Constraints		None	375	310
Optimal net benefits			US $ 780.1	

Table 7. The optimal solution to the fallow and biomass linear programme for proposed practice

Variable	Soil Management Option	Land (Ha)	Investment Costs (US $)	Labour (Labour days)
A	Farmers Practice	0	0	0
B	1.8 t ha^{-1} Tithonia	0	0	0
C	0.9 t ha^{-1} Tithonia + N	0.422	148.3	142.7
D	N+ P + K	0.494	226.5	167.0
E	Natural fallow	0	0	0
F	Natural fallow P + K	0	0	0
G	50% Canavalia	0	0	0
H	50% Mucuna	0	0	0
I	100% Mucuna	0	0	0
Resource utilization under optimal solution		0.916	374.8	309.7
Constraints		None	375.2	310
Optimal net benefits			US $ 713.5	

Table 8. Linear programming output for the farmers practice

Variable	Treatment	Value	Reduced cost
A	Farmers Practice	0.900	0.000
B	1.8 t ha^{-1} Tithonia	0.963	0.000
C	0.9 t ha^{-1} Tithonia + N	0.000	3.667
D	Natural fallow	0.000	61.263
E	Natural fallow P + K	0.000	136.921
F	50% Canavalia	0.000	101.737
G	50% Mucuna	0.000	78.423
H	100% Mucuna	0.000	93.513
Row	Constraint	Slack/ Surplus	Dual prices/shadow prices
2	Investment costs (US$)	0.000	0.501
3	Labour (labour days)	0.000	1.91

Table 8. Linear programming output for the proposed practice

Variable	Treatment	Value	Reduced cost
A	Farmers Practice	0.000	92.631
B	1.8 t ha^{-1} Tithonia	0.000	115.411
C	0.9 t ha^{-1} Tithonia + N	0.422	0.000
D	N+ P + K	0.494	0.000
E	Natural fallow	0.000	303.156
F	Natural P + K	0.000	312.602
G	50% Canavalia	0.000	348.354
H	50% Mucuna	0.000	300.656
I	100% Mucuna	0.000	186.702
Row	Constraint	Slack/ Surplus	Dual prices/shadow prices
3	Investment costs (US$)	0.000	0.166
4	Labour (labour days)	0.000	2.10

Table 9 The sensitivity analysis of the optimal solution for the farmer’s practice

Variable	Soil Improvement Practice	Objective Function Coefficient (US$)	Objective Function Ranges (US$)
A	Farmers Practice	397.3	393.97 – 409.83
B	1.8 t ha^{-1} Tithonia	438.4	426.42 – 490.21
C	0.9 t ha^{-1} Tithonia + N	514.2	Unlimited – 517.87
D	Natural fallow	195.0	Unlimited – 256.26
E	Natural Fallow P + K	201.5	Unlimited – 338.42
F	50% Canavalia	262.2	Unlimited – 363.9
G	50% Mucuna	304.1	Unlimited – 382.5
H	100% Mucuna	337.5	Unlimited – 431
Resource Constraints		Constraint Coefficient	Constraint Ranges
Investment costs (US$)		375.2	346.03 – 400.79
Labour I (labour days)		310	290.2 – 336.1

[T]able 10. The sensitivity analysis of the optimal solution for the proposed practice

Variable	Soil Improvement Practice	Objective Function Coefficient (US$)	Objective Function Ranges (US$)
A	Farmers Practice	566.0	Unlimited – 658.63
B	1.8 t ha^{-1} Tithonia	647.6	Unlimited – 763
C	0.9 t ha^{-1} Tithonia + N	768.8	670.7 – 786.5
D	N+ P + K	786.3	768.6 – 1,002.8
E	Natural fallow	290.6	Unlimited – 593.8
F	Natural P + K	351.4	Unlimited – 664
G	50% Canavalia	461.4	Unlimited – 809.7
H	50% Mucuna	527.0	Unlimited – 827.7
I	100% Mucuna	587.1	Unlimited – 773.8
Resource Constraints		Constraint Coefficient	Constraint Ranges
Investment costs (US$)		375.2	322.2 – 420.2
Labour I (labour days)		310	276.7 – 361

Results and discussion

The Farmers Practice

The profitability analysis shows that the biomass transfer practice in general had almost twice the average net benefit (US$ 408.1) of the improved fallow (IF) treatments (US$ 265.1), attributed to higher average costs for the latter practice (Table 2). The 100% Mucuna treatment would produce the highest net benefits despite the high total variable costs (TVC) of US$ 348 in the IF treatments. The high net benefits from this treatment, is attributed to the high yields of 3.7 t ha^{-1}. The marginal rate of return, (MRR) analysis eliminated the 100% Canavalia treatment, because it had dominating costs (Table 2). The natural fallow had the lowest net benefits (US $195).

In the BT practice, 0.9 t ha^{-1} Tithonia and 30 kg $ha^{-1}$of inorganic nitrogen (Table 2) had the highest net benefits of US $ 514. Despite this, the MRR analysis selected 3 treatments from the BT SIP in comparison to the 5 selected from the IF SIP because IF had a lower average labour utilization than the BT despite the 3 seasons of this practice. Also, in the IF treatment, with increasing costs, net benefits increased accordingly.

The optimal treatments selected by the LP analysis were the farmers practice and 1.8 t ha^{-1} Tithonia treatment that would produce an optimal net benefit of US$ 780 (Tables 6 and 8) over two seasons. The farmer would grow 0.9 ha of maize using the usual practice of no amendments and an investment cost of US$ 162 and 145 labour days. Treatment B (1.8 t ha^{-1}tithonia) would incorporate 60 kg^{-1} of nitrogen into the soil from the organic nutrient source. The total land requirement for these two treatments would be 1.9 Ha. The implication for this optimal treatment is that the farmer could rotate the soil improvement treatment with the farmers practice to replenish the nutrient status where the farmers practice has been located and the use of inorganic fertilizers is eliminated and supplemented with the use of available labour. No fallow treatment was included from the IF treatment in the optimal solution. A higher net benefit would also be got from the farmers' scenario of only valuing selected labour activities; however, this optimal solution could only be limited to one SIP.

The sensitivity analysis shows that the optimal solution for the farmers practice could be maintained in the solution between net benefit ranges of US $ 394 and 410 and US $ 426 – 490 for the 1.8 t ha^{-1} Tithonia treatment. Labour and Capital resources were completely utilized. The sensitivity analysis (Tables 9 and 10) shows that an additional investment of US $75 and 26 labour days could be made while still maintain the optimal solution. The labour had a shadow price of US $1.91(Table 10). This was higher than the daily labour wage rate of US $ 1 day^{-1}, but lower than the returns to labour for the two treatments (US $ 3.30 and 3.59 from treatments A and B respectively (Table 2) indicating that the farmer is ripping a profit from the investment in labour hired. However, while the hired labour should be valued at its shadow price (US $1.91), the farmer's scenario does not take care of the opportunity cost of family labour. While Lewis (1954) agrees that the marginal value product of unused labour from non-peak seasons is equal to zero, White et al. (2004) dispute this, because other labour activities could be conducted that could be crucial to the overall farm income. These include community social activities. In Osukulu and Kisoko sub-counties, some of the farmers extra income is generated from the cross border trade of farm produce (Livestock) and non-farm produce (Alcoholic beverages and molasses), community activities such as market days, and building social capital through group activities.

The Enterprise Scenario

In the enterprise scenario with all labour valued, again, 100% Mucuna had the highest discounted net benefits (Table 4) with the 100% Canavalia having dominating costs for the IF treatments. In the BT SIP, the N+P+K had non-dominating costs and was included in the Marginal analysis. In the farmers' scenario however, this treatment had dominating costs. This could be attributed to the higher yields and the prices associated with the latter treatment and the benefits increasing with the increase in the costs. The N+P+K SMO had the highest yields in both SIP followed by the 0.91 t ha^{-1} Tithonia + N treatment, whilst the lowest yields were from the natural fallow (1.9 t ha^{-1}). The 1.8 t ha^{-1} Tithonia + P+K had the highest labour utilization in both SIP (US $ 350).

The optimal solution (Table 7) for the proposed practice produced a US$ 66.6 lower net benefit (US $714) over two seasons than the farmers practice; however, it selected more treatments (C and D) on 0.916 ha of land. N+P+K SMO was allocated the highest amount of land (0.494 ha) than 0.9 t ha^{-1} Tithonia + 30 kg ha^{-1} Nitrogen (0.422ha). The objective function can rise up to over US $1,000 (Table 13) for the purely inorganic option (N-P-K) while maintaining the optimal solution. The shadow price of labour is even higher for the proposed practice solution implying the competitive uses for the associated labour. The returns to labour are still higher than the opportunity cost of labour.

CONCLUSIONS

Given that farmers treat their farms as enterprises, soil management practices can be used for the two scenarios and in both, all SMO's were profitable, suggesting the possibility of adoption by farmers. This is further evident by the returns to land and labour resources. Given the farmers' labour and capital investment constraints, however, more could be invested for both scenarios to maintain the optimal solution. The market value of labour is valued at below its actual price as seen by the sensitivity analyses; however despite this the returns to labour are still high. In the farmers practice scenario, the option of the sole Tithonia is given on a larger area of land. This optimal treatment lays emphasis on labour requirements. On the other hand, the proposed practice includes the integrated use of nutrients with half the land area to compensate the investments cost in the inorganic fertilizers. The implications are that the use of INM can be afforded on smaller land areas or the farmer has an option to use purely organic nutrient sources. The use of tree and shrubs for integrated soil fertility replenishment is recommended given that the farmers are enterprise oriented and use smaller land areas to economise on resources.

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