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Economic Evaluation of Organic and Inorganic Sources of Nitrogen under Striga Infestation in Western Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. Author RON designed the study, wrote the protocol and collected the data. Author DGO analyzed the data. Authors CCS and COO wrote the first draft of the manuscript. All authors undertook literature search and interpretation of the results. All authors read and approved the final manuscript.

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ABSTRACT

Due to escalating cost of imported fertilizers, there is renewed interest in the use of local nutrient resources in managing soil fertility in Kenya. The effect of integrated use of urea and Calliandra or maize stover on maize yields, financial benefits was assessed in a field experiment carried at Nyabeda in western Kenya. Urea and Calliandra or maize stover were combined in a way to supply N at 75 kg ha^{-1} from both sources in 100:0, 80:20, 60:40, 40:60, 20:80, 0:100, 0:0 ratios arranged in randomized complete block design (RCBD) with 12 treatments replicated four times in five consecutive seasons. Gross margins and benefit cost ratios were used for the analysis.

Overall, maize stover (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) and *Calliandra* (45 kg N ha^{-1}) combined with urea (30 kg N ha^{-1}) gave the highest mean total biomass yields of 8.3 and 7.9 t ha^{-1} respectively. The two treatments out yielded the control by 89 and 80% respectively. The control and sole maize stover (75 kg N ha^{-1}) had the lowest yields across all the seasons.

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The highest net benefits (71 USD) were recorded under maize stover (45 kg N ha^{-1}) combined with urea (30 kg N ha^{-1}) followed by Calliandra (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) at (68 USD). Sole application of maize stover gave the lowest benefit (-553 USD). Calliandra (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) was the only treatment that had a benefit: cost ratio approaching 2, and therefore, the most likely of the tested technologies to be adopted by farmers. These results suggest that the use of both Calliandra and maize stover with modest amount of inorganic fertilizers (urea) is more profitable than sole use of either of the two N sources.

Keywords: Economic analysis; cost benefit ratio; integrated soil fertility management; Striga.

1. INTRODUCTION

In sub-Saharan Africa (SSA) the parasitic weeds in the genus *Striga* are a serious constraint to the productivity of staple cereal crops such as maize (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench.], pearl millet [*Pennisetum glaucum* (L.) R. Br.], and upland rice (*Oryza sativa* L.) [1,2]. The most important among the Striga species in Africa are purple witchweed *[Striga hermonthica* (Del.) Benth.] and Asiatic witchweed [*Striga asiatica* (L.) Kuntze] [3,4]. Striga spp. infestation is most severe in areas with low soil fertility and low rainfall and farming systems characterized by intensive cultivation with poor crop management and less use of inputs such as fertilizer, pesticides, and improved seeds [5]. *Striga hermonthica* has the potential to threaten food security in many countries and is particularly significant in Africa [6]. It decimates maize which is the main staple food crop for close to 300 million people in Africa [7,1] with yield loss estimated at 10 million tons grain worth $ US 7 billion [8,9]. *Striga* infests about 217,000 hectatres (about 15% of the arable land) in the Lake Victoria basin of Kenya [10], causing annual crop losses estimated at $53 million [11]. Results of a survey done on 83 farms in Western Kenya revealed that 73% of the farms are severely infected with *S. hermonthica* [11]. The potential maize yield in the Western Kenya is 4-5 t ha^{-1} [12] with the average yield loss attributed to *Striga* infection being 1.15 tons per hectare for maize [13]. Striga spp. survive by siphoning off water and nutrients from the host crop for its own growth and exerts a potent phytotoxic effect. It impairs normal host-plant growth, resulting in a large reduction in plant height, biomass, and eventual grain yield [14]. *Striga* weeds are known to cause crop yield losses of between 20 - 100% for maize [15,16,12] and 20-50% in sorghum [17,16] although 100% yield loss is not uncommon. Smallholder famers in western Kenya rely on maize as the staple food crop but its production is low estimated at 0.5 to 1.5 t ha^{-1} yr^{-1} against a production potential of 4 t ha^{-1} [18].

In Western Kenya a number of technologies for the management of Striga such as Push pull have: [12]; use of leguminous plants [19] and integrtaed soil fertility manangment [20]. For effective disemination of these technologies, an economic evaluation is necessary inorder to determine the benefits against the added input costs. Integrated soil fertility management involving the combined use of organic and mineral resources, resilient germplasm and nutrient cycling and conservation [21] is an overarching approach to restoring and maintaining soil productivity, and has been reported to result into synergy and improved conservation and synchronization of nutrient release and crop demand, leading to increased fertilizer use efficiency and higher yields [22]. Integrated Soil Fertility Management has been demonstrated as a strategy that can address the complexities and peculiarities of soil fertility management on smallholder farms, help low resource endowed farmers mitigate problems of poverty and food insecurity by improving the quantity of food, income and resilience of soil productive capacity [23]. Although previous research on integrated soil fertility has come up with technologies that have produced higher yields, however, little work has been done on costs and benefits associated with the use of such technologies under *Striga* infestation. The objecticve of this study was to ccompare the economic benefits of application of *Calliandra* or maize stover with urea for maize production under *Striga* infestation.

2. MATERIALS AND METHODS

2.1 Experimental Site

This study was conducted at Nyabeda (N 0° 08', E 34° 24') in Siaya District of western Kenya. The area is classified as a midland with an altitude of approximately 1330 m above sea level [24]. The rainfall distribution pattern is bimodal, allowing two cropping seasons a year with the long rains starting from March and ending in July and the short rains commencing from August and ending in November, with an annual mean of 1800 mm. Mean annual temperature ranges between 22^{0}C and 24^{0}C. The soils are clayey, reddish, deep and well drained and are classified as Ferralsols (Kandiudalfic Eutrudox), [24].

2.2 Experimental Design, Establishment and Management

The experiment was laid out in a randomized complete block design (RCBD) with twelve treatments replicated four times for five seasons (2007-2009). Treatments consisted of two organic sources of N (maize stover and residues of *Calliandra calothyrus* Messn.) and urea as the inorganic mineral source of (N). Treatments were combined in the following ratios i.e 100:0, 80:20, 60:40, 40:60, 20:80, 0:100, 0:0 so as to supply a total of 75 kg N ha^{-1} per treatment except the control i.e treatment 0:0 where no N inputs were applied (Table 1). Maize stover was obtained from neighbouring farms and *Calliandra* from an established demonstration plot within the area. In each season before their use, a sub sample of each organic input was anayzed for N content to determine the quantity to be applied. The plant residues were then weighed, chopped and incorporated into the soil at a depth of 15 cm during land preparation in all seasons. Phosphorus (P) and potassium (K) were uniformly applied to each plot of 6m x 6m at the rate of 40 kg P and 20 kg K ha^{-1} as triple super phosphate and muriate of potash respectively at the beginning of each season. One day after treatment application, maize variety WH502 was planted at a spacing of 75 cm between rows and 25 cm within rows. Two seeds were planted per hill and thinned to one seedling per hill two weeks after emergence (WAE) to give a total maize population of 53,333 plants ha^{-1}. Weeding was done at three and eight weeks after planting. Urea was applied in splits with one third being applied at planting while the rest was applied as a topdress six weeks later.

2.3 Economic Analysis

Cost and benefits associated with each treatment were compared using partial budgeting, which included only costs and benefits that varied from the control, i.e. costs of inputs and increased maize yield [25]. The values of the costs used are presented in Table 2. The prices of maize, and urea and fertilizer transport costs were determined through a market survey in the area. Amounts of labour for application of fertilizer, stover and Calliandra were determined from findings of [26] and observation of the performance of specific activities in each season. Discount rate of capital was estimated at 10% per season (20% per year) and applied only to cash costs [27]. This discount rate reflects a farmer's preference to receive benefits as early as possible and postpone costs. The net benefit for each treatment was determined as the difference between added benefits and added costs. Calliandra and maize were costed in terms of labour involved in their harvesting, transportation and incorporation [25]. To evaluate the economic benefits of the use of nutrient inputs, the benefit cost ratio (BCRs), calculated as the value of the additional maize yield after application of the nutrient input divided by the cost of the nutrient inputs to achieve this, were used [28].

Table 1. Description of treatments used in the field trial

Treatment No	Organics	Nitrogen from organic sources	Nitrogen from Urea	Total Nitrogen
		(kg ha^{-1})		
1	None	0	0	0
2	*Calliandra*	75	0	75
3	*Calliandra*	60	15	75
4	*Calliandra*	45	30	75
5	*Calliandra*	30	45	75
6	*Calliandra*	15	60	75
7	Maize stover	75	0	75
8	Maize stover	60	15	75
9	Maize stover	45	30	75
10	Maize stover	30	45	75
11	Maize stover	15	60	75
12	None	0	75	75

Table 2. Values used for cost benefit analyses

Parameter	Value (USD) #				
	2007LR	2007SR	2008LR	2008SR	2009LR
Price of urea (USD kg^{-1})	0.90	1.3	1.8	2.1	1.9
Price of TSP(USD kg^{-1})	1.5	1.7	2.2	2.9	3.6
Price of MOP(USD kg^{-1})	1.3	1.4	2.1	2.3	2.1
Transport of fertilizer to homestead/farm	1.75	1.75	1.75	1.75	1.75
Labour cost					
Baseline labour cost of fertilizer application /ha^{-1}	1.37	1.37	1.37	1.37	1.37
Labour cost of application of additional fertilizer ha^{-1}	0.30	0.30	0.30	0.30	0.30
Baseline labour cost for Calliandra application	5.88	5.88	5.88	5.88	5.88
Cost of cutting and application of 10 tons stover	430	430	430	430	430
Price of maize (kg^{-1})	0.32	0.32	0.32	0.40	0.22

2.4 LR and SR are Long and Short Rains Resperctively

#Exchange rate of 75 Kenya Shillings = 1 US dollar (USD) at the time of experimentation. § values of *Calliandra calothyrsus* is expressed on dry weight basis.

Dominance analysis approach was applied to rank order and scale the different treatments in terms of their TVCs; a treatment would be regarded to dominate another if it is more costly. The study picked the least dominant ones and computed the marginal rate of return (MRR) which shows the rate of return a farmer stands to gain by producing a single additional unit; as long as MRR is greater than 1, a profit is made by producing one additional unit.

3. RESULTS AND DISCUSSION

3.1 Relationship between *Striga* Density and Maize Grain Yield

The overall experiment showed that *Striga* incidence had detrimental effect on maize yield and yield parameters. The total biomass yield reduced as a result of *Striga* by an average of 6.5 tha^{-1} for each 1 unit increase in log-transformed *Striga* infestation in Calliandra, while maize grain yield declined by an average of 2.9 t ha^{-1}. Reduction in crop yields realized from *Striga* infestation result from competition for C assimilates, water, mineral nutrients and amino acids [29]. Apart from parasitism, *Striga* impairs photosynthetic efficiency, normal plant growth, resulting in large reduction in height, biomass and eventual growth yield [30].

3.2 Maize Grain Yields

Overall maize stover (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) and Calliandra (45 kg N ha^{-1}) combined with urea (30 kg N ha^{-1}) had the highest mean grain yields of 3.0 and 2.7 t ha^{-1}, respectively [20]. Maize stover (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) increased maize grain yields relative to the control by 275%, 107% and 155% in the first, second and third seasons respectively. Calliandra (45 kg N ha^{-1}) combined with urea (30 kg N ha^{-1}) increased maize grain yields relative to the control by 191%, and 233% in the first and third seasons, respectively [20]. Because the short rain seasons of 2007 and 2008 were not significantly different, they are not used in the determination of the cost-benefit values.

3.3 Economic Analysis

Total variable costs (TVC) were high for the treatments where stover was applied in all seasons (Table 3). Averaged across the five seasons, sole maize stover had the highest TVC of (535 USD ha^{-1}) while sole urea had the lowest (319 USD ha^{-1}). Total variable costs of using the OM when applied alone were higher than using urea alone. The variable costs for integrating the inorganic and organic sources of nutrients were in between the extremes. The higher costs for the OM treatments resulted mainly from the high labour cost associated with their use because of the large amounts that had to be harvested and applied. For example, approximately 8.33 t ha^{-1} of fresh Calliandra biomass was required to supply 75 kg N per ha^{-1}. At the practical farming level, the labour costs for harvesting, transporting and incorporating it were therefore quite high. These costs are likely to further increase if many farmers were to adopt the Calliandra biomass transfer technology as the amount of Calliandra available will not be sufficient to meet the demand. Added costs for the use of maize stover were also high mainly because of the low N (0.65 %) content of the stover used in this study. At the rate of 75 kg N per ha^{-1} used in this study, almost 12.5 t ha^{-1} of maize stover was applied.

Averaged across seasons, the highest net benefits (71 USD) was obtained with maize stover (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) followed by Calliandra (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) (68 USD) (Table 4). Sole maize stover recorded the lowest net benefit (-553). In all seasons, treatments in which maize stover supplied at 45 kg N ha^{-1} or more had negative net financial benefits. This may be attributed to the high labour costs and associated low yields due to N immobilization [31]. However, when the maize stover was used to provide only 30 kg N ha^{-1} or less, the financial benefits were generally positive indicating that the increase in yields as a result of increasing rate of urea in the combination was enough to offset the added costs associated with the integration. Net financial benefits were low in the second and fourth seasons mainly due to low grain yields realized in these seasons. Adequate extra yield that would offset the high costs of using organic residues and allow subsequent economic benefit was hardly achieved under the prevailing low rainfall conditions of the second season. Similar season specific responses have been reported by others [32].

Table 3. Total variable costs associated with different treatments at Nyabeda

Treatment	2007LR	2007SR	2008LR	2008SR	2009LR	Average TVC	Average labour %
75CC+0U	340(93)	340(93)	350(90)	330(96)	337(94)	339	93
60CC+15U	334(80)	338(79)	360(74)	359(75)	367(73)	351	76
45CC+30U	320(65)	330(63)	340(64)	349(62)	337(55)	343	62
30CC+45U	298(50)	308(48)	264(63)	290(57)	385(38)	309	51
15CC+60U	267(29)	291(27)	383(20)	394(20)	383(20)	344	23
75MS+0U	505(100)	511(100)	546(95)	559(92)	555(93)	535	96
60MS+15U	445(94)	459(91)	520(80)	522(80)	515(81)	492	85
45MS+30U	399(80)	406(78)	470(68)	487(65)	473(67)	447	72
30MS+45U	340(64)	359(61)	445(49)	468(47)	455(48)	413	54
15MS+60U	278(42)	317(37)	410(29)	428(28)	422(28)	371	33
75U	213(1)	251(1)	355(1)	394(1)	382(1)	319	1

CC=Calliandra, MS =maize stover, U=urea, LR=long rains, SR=short rains
Figures in parenthesis indicate the proportion in percentage of labour costs make of the total variable costs of using specified technologies

Table 4. Net Benefits in USD per hectare of maize for the treatments at Nyabeda

Treatment	2007LR	2007SR	2008LR	2008SR	2009LR	Average net benefit	Overall ranking
75CC+0U	-208	-182	188	-126	-16	- 68	4
60CC+15U	-253	-129	-25	-254	-95	-151	8
45CC+30U	209	-20	208	-154	9	50.4	3
30CC+45U	83	38	124	18	76	68	2
15CC+60U	-65	-154	100	-148	-231	-100	5
75MS+0U	-512	-518	-547	-614	-573	-552	11
60MS+15U	-460	-458	-526	-521	-514	- 495	10
45MS+30U	-393	-405	-499	-485	-472	- 450	9
30MS+45U	437	23	-44	-165	102	71	1
15MS+60U	-16	-137	182	-167	-378	-103	6
75U	88	-92	43	-281	-329	-114	7

CC=Calliandra, MS =maize stover, U=urea, LR=long rains, SR=short rains

The benefit cost ratios (BCRs) were low and varied between seasons and treatments (Table 5). None of the treatments gave a BCR of 2 and above which is considered the minimum that should be attained if a farmer has to adopt a particular soil fertility technology [33]. The decision by farmers to use fertilizers sources, based on the BCR indicator, depends on their own standard of profitability [33]. However, the general rule is that a BCR of at least 2 is attractive to farmers because for every one unit invested in production, the farmer is able to recover it and also earn another unit that goes to meeting other indirect costs including return to equity [25,34,33]. Despite the good agronomic performance by Calliandra on maize yields, it is unlikely that farmers could adopt its use as a source of N for maize mainly because of its high labour costs. The general reluctance by farmers to adopt use of ISFM technologies in the study are appears therefore to be justified.

Dominance analysis led to selection of non-dominated treatments which were ranked in order of increasing TVC for further analysis. Calliandra (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) and maize stover (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) were non-dominated and remained as promising soil fertility management options under the prevailing market prices (Table 6). Changing from Calliandra (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) to maize stover (30 kg N ha^{-1}) combined with urea (45 kg N ha^{-1}) resulted in marginal rate of return (MRR) of 2.88%. This was occasioned by a relatively low increase in net benefits (USD 3) and minimal increase in marginal costs (USD 104). The most economically viable option was not necessarily the one with the highest net benefits or yield. As a guideline, an MRR below 100 is considered low and unacceptable to farmers [25]. This is because such a return would not offset the cost

Table 5. Benefit-cost ratio for the treatments at Nyabeda

Treatment	Season					Average BCR
	2007LR	2007SR	2008LR	2008SR	2009LR	
75CC+0U	0.3	0.4	1.4	0.6	0.9	0.7
60CC+15U	0.1	0.6	0.8	0.2	0.7	0.5
45CC+30U	1.5	0.9	1.5	0.5	0.9	1.1
30CC+45U	1.2	1.0	1.3	1.0	1.2	1.1
15CC+60U	0.6	0.4	1.2	0.6	0.3	0.6
75MS+0U	0.04	0.03	0.1	0.3	0.2	0.1
60MS+15U	0.4	0.2	0.3	0.3	0.4	0.3
45MS+30U	0.7	0.5	0.8	0.5	0.9	0.7
30MS+45U	1.9	1.0	0.8	0.5	1.2	1.1
15MS+60U	0.9	0.5	1.3	0.5	0.02	0.6
75U	1.3	0.6	1.0	0.2	0.02	0.6

CC=Calliandra, MS =maize stover, U=urea, LR=long rains, SR=short rains

Table 6. Dominance and marginal analyses of soil fertility options at Nyabeda

Treatment	TVC	NBV	MC	MR	MRR
30CC+45U	309	68			
75U	319	-114D			
75CC+0U	339	-68D			
45CC+30U	343	50.4D			
15CC+60U	344	-100D			
60CC+15U	351	-151D			
15MS+60U	371	-103D			
30MS+45U	413	71	104	3	2.88
45MS+30U	447	-450D			
60MS+15U	492	-495D			
75MS+0U	535	-553D			

CC=Calliandra, MS =maize stover, U=urea, LR=long rains, SR=short rains, D=dominated, TVC=Total variable Costs, NPV=Net Present Value, MC=Marginal Cost, MR=Marginal Return, MRR=Marginal Rate of Return of capital and other transaction costs while still providing an attractive gross margin to serve as an incentive.

4. CONCLUSION AND RECOMMENDATIONS

In poor soils such as those of western Kenya, applying N in the form of urea, or higher quality organic resources or their combination is very crucial for maize production. The optimum application Maize stover applied at 30 kg N ha^{-1} plus urea at 45 kg N ha^{-1} and *Calliandra* applied at 45 kg N ha^{-1} plus urea at 30 kg N ha^{-1} gave the highest mean yields and may therefore be recommended as optimum applications under the western Kenya conditions. During the five seasons, maize stover at 45 kg N ha^{-1} + 30 kg N ha^{-1} urea gave the highest (71 USD) followed by Calliandra at 30 kg N ha^{-1} + 45 kg N ha^{-1} urea with (68 USD) gave the highest net benefit and the sole maize stover had the lowest. On the other hand, the recommended rate of inorganic fertilizer gave the highest return to labour while sole maize stover gave the lowest. From partial budgets, it was observed that treatments with highest yields were not necessarily the most economical. Since organic materials may not be available in large amounts that are required for sole application, farmers are encouraged to adopt integration of the organic and inorganic as they have higher maize grain yields, net benefit and return to labour.

The NPV for using sole maize stover was negative throughout the duration of study. This means that farmers who solely depend on maize stover are incurring losses in maize production and should be advised to find alternative use of invested labour. Financial benefits were mostly negative in *Striga* infested area. The main options available for farmers under such conditions is to use additional urea beyond the 75 kg N ha^{-1} or resort to other soil enriching options such as intercropping maize and sorghum with *Desmodium* species. Farmers have the option of using fast maturing, drought and *Striga* tolerant maize varieties.

The study show that broad recommendations that assume homogeneity of farming conditions are not suitable in the study site and demonstrates that agronomic results alone do not provide a complete picture when assessing a given technology and needs to be supplemented by economic analysis. Therefore, to enhance adoption, there is need for targeting of recommendations to groups of farmers who share similar circumstances and involve them in research process. It is recommended that the promising soil fertility improvement options be evaluated on high value crops, especially horticultural crops, which have high potential of improving MRR and being acceptable to farmers.

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COMPETING INTERESTS

Authors have declared no competing interests exist.

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