American Journal of Experimental Agriculture
4(1): 80-89, 2014

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An Agronomic and Economic Evaluation of Integrated use of *Calliandra callothyrsus* and Maize Stover with Urea in Western Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Author RON designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author PAO managed the analyses of the study and. the literature searches. Both authors read and approved the final manuscript.

Original Research Article

Received 15th August 2013
Accepted 25th September 2013
Published 21st October 2013

ABSTRACT

The agronomic effectiveness of integrating organic and inorganic nutrient sources has been demonstrated in Kenya but economic analysis is often lacking in such studies thus denying farmers the information required to make informed choices. We investigated the effect of two organic materials; leafy biomass of *Calliandra callothyrsus* (calliandra) or maize stover and urea on maize yield and economic benefits for three consecutive seasons at Bukura in western Kenya. A randomized complete block design with the following organic material:urea combinations were used so as to supply 75 kg N ha^{-1}; 75:0, 60:15, 40:35, 35:40, 15:60 and 0:75. A control treatment where no nutrient inputs were applied was included. Economic analysis was conducted using partial budgeting. The highest increase in maize yields relative to the control in the first (107%) and third seasons (142%) was with calliandra (30 kg N ha^{-1}) applied with urea (45 kg N ha^{-1}) while in the second season (163%) it was calliandra (45 N ha^{-1}) combined with urea (30 kg ha^{-1}). Maize failed to respond to maize stover when applied alone (75 kg N ha^{-1}) or in combination with low rates of urea but only responded when the rates of N from urea in the combination were higher than the N from the maize stover likely due to N immobilization. The highest net benefits were obtained with Calliandra (30 kg N ha^{-1}) plus urea (45 kg N ha^{-1}) in all the

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seasons. None of the treatments gave a benefit cost ratio (BCR) of > 2 which is considered adequate if a farmer has to adopt a particular technology. Thus despite the good agronomic performance obtained by combining calliandra (30 kg N ha^{-1}) with urea (45 kg N ha^{-1}), it is unlikely that farmers would adopt the practice mainly because of the high labour costs involved.

Keywords: Calliandra; maize stover; net benefits; urea; Western Kenya.

1. INTRODUCTION

Kenya is among the few countries in the world where poverty is increasing rather than declining and where human development indicators are worsening [1]. This poses a major challenge to the achievement of the Millennium Development Goals (MDGs) by 2015. There is a strong nexus between Agriculture and several of the MDGs such as those related to poverty in general, hunger, health, child mortality, as well as environmental sustainability. Indeed, Agriculture remains the mainstay of Kenya's economy yet per capita food production has continued to decline over the past two decades thus posing a serious threat to food security. Staple cereal crop yields in many smallholder communities have remained < 1 t ha^{-1}, despite the good climate in some areas [1,2]. Over the years, considerable efforts have been made amongst researchers to analyze this crisis and its root causes. [2] concluded that soil fertility depletion is the fundamental biophysical root cause of declining per capita food production in many parts of Africa. With population continuing to increase in many parts of Kenya, the need to reverse these declining trends has become more urgent.

Efforts and approaches to replenish soil fertility in Kenya are well documented [3]. Although judicious application of inorganic fertilizers is recognized as the most effective way for overcoming soil fertility decline or alleviating nutrient deficiencies, their high cost, inaccessibility, and generalized recommendations resulting in low, erratic and unprofitable crop responses limit their use, particularly on smallholder farms in eastern Africa [4]. A paradigm shift in soil fertility management towards the integrated soil fertility management (ISFM) has been proposed [5]. Integrated Soil Fertility Management is the application of locally adapted soil fertility management practices to optimize the agronomic efficiency of fertilizer and organic inputs in crop production [5]. Its technical backbone is the judicious combination of organic and inorganic sources of nutrients.

In the last two decades, intensive soil fertility replenishment research has been conducted in western Kenya by organizations such as Kenya Forestry Institute (KEFRI), International Center for research in Agroforestry (ICRAF) and Tropical Soil Biology and fertility programme (TSBF). A wealth of knowledge and technologies that form part of the ISFM strategy to mitigate soil fertility depletion were generated and are available. However, the recommendations did not take into account the dynamic nature of the agricultural input and output prices and other economic changes [6] which influence the uptake of technologies by farmers. This has rendered many of the recommendations irrelevant to farmers, and hence their low adoption rates. There is need therefore to revise the current soil fertility management recommendations such that they take into account the cropping systems and the profitability of nutrient inputs. This will enable farmers to make informed choices when deciding on which soil fertility technologies to adopt. This study therefore aims at extending this evaluations by testing two of the most common organic materials in western Kenya; maize stover and *Calliandra callothyrsus* (hereafter referred to as calliandra) as sources of N for maize. Calliandra is a leguminous tree whose leaves have a high nitrogen content and can therefore be used as a soil fertility amendment or livestock feed [2]. It is recognized that the main limitations of using organic inputs for soil fertility management is their low nutrient content and hence they have to be applied in very large amounts. However, the quantities available on most smallholder farms are often inadequate and therefore the need to integrate them with inorganic fertilizers such as urea has been recommended [7]. There is however paucity of information on the most efficient combinations between the inorganic and organic sources of nutrients mainly because appropriate experimental designs have not been used [8]. The objective of this study was therefore i) to determine the effects of applying different rates of two organic materials; *Calliandra callothyrsus* or maize stover and a commercial fertilizer, urea on maize grain yield and ii) compare the economic benefits of application of *Calliandra* or maize stover with urea for maize production.

2. MATERIALS AND METHODS

2.1. Study Site

A field experiment was conducted for three consecutive seasons, from March 2008 to August 2009 at Bukura (N 0° 20', E 34° 15') in west ern Kenya. The site is at an altitude of approximately 1430 m asl. and receives bimodal rainfall, with long rains occurring from March to June and the short rains from August to November with a mean annual rainfall is 1800 mm. The soils at the site are classified as Orthic Luvisols [9]. The soil was low in N (< 0.2%) and P (<10 mg kg^{-1}) (Table 1). The organic matter level, as reflected by % organic carbon was also low (< 2%) [10]. The soil pH was however conducive for maize growth. The site was chosen due to its demographic and agro-ecological characteristics, which are broadly representative of the situation found in other tropical highlands of East Africa.

Table 1. Some selected chemical and physical characteristics of the soils at Bukura

Parameter	Value
pH (1:2.5 soil: water)	6.5
Exchangeable acidity ($cmol_c$ k g^{-1})	0.10
Organic carbon %	1.25
Total N %	0.15
Exchangeable Ca ($cmol_c$ kg^{-1})	5.87
Exchangeable Mg ($cmol_c$ kg^{-1})	1.97
Exchangeable K ($cmol_c$ kg^{-1})	0.22
Olsen extractable P (mg kg^{-1})	7.7
Clay (%)	16
Sand (%)	65
Silt (%)	19

2.2 Experimental Layout and Management

The experiment was laid out in a randomized complete block design with twelve treatments replicated four times with plots of 6 m x 6 m in size. A substitution type of experiment was used whereby the total N rate was fixed at the recommended rate of 75 kg ha^{-1} for maize in the study area [11]. The following organic material:urea combinations were used so as to supply 75 kg N ha^{-1}; 75:0, 60:15, 40:35, 35:40, 15:60 and 0:75 (Table 2). A control treatment where no nutrient inputs were applied was included. The two OMs represent common alternatives to inorganic fertilizers on smallholder farms, but vary in their chemical characteristics (Table 3).

Table 2. The experimental treatments

Treatment no	Organic material	N from organics	N from urea	Total N
			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

The organic materials were analyzed to determine their chemical characteristics which are presented in Table 3. The N content was used to calculate the rates of the organic materials to be applied.

Table 3. Selected chemical characteristics of the organic materials

Organic material	Parameter								
	%N	%P	%K	%Ca	%Mg	%C	% Polyphenol	%Lignin	C:N
Calliandra	3.0	0.09	0.59	0.56	0.15	45	14	25	15
Maize stover	0.65	0.05	0.81	0.29	0.22	42	0.95	5.3	65

The appropriate rates of organic materials were weighed, chopped and incorported into the soil at a depth of 15 cm one day prior to planting in all the seasons. The first season was from March to August 2008, the second season from August to December 2008 and the third season from March to August 2009. In the appropriate treatments, urea was applied in splits with one third being applied at planting time while the rest was applied as a topdress six weeks later. Phosphorus and potassium were uniformly applied to all plots at the rate of 40 kg P and 20 kg K ha^{-1} as triple super phosphate and muriate of potash respectively at planting time in each season to ensure that P and K were not limiting factors while studying the N effects [11]. Commercial maize variety WH 502, commonly grown by farmers in the area, was planted as a test crop at a spacing of 75 cm between rows and 25 cm within the rows. It has a yield potential of 8 t ha^{-1} and matures within five months. Two seeds were planted per hill and later thinned to one seedling per hill two weeks after emergence to give a total maize population of 53,333 plants ha^{-1}. The maize was managed using the recommended agronomic practices for the area and harvested at maturity.

All the maize grain yield data were subjected to Analysis of Variance (ANOVA) using the Genstat statistical package [12] to determine the effects of treatments. The standard error of difference between means (*s.e.d.*) was used to compare the treatment means. Mention of statistical significance refers to p = 0.05 unless otherwise stated.

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 [13]. The values of the costs used are presented in Table 4. 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 [14] and observation of the performance of specific activities in each season. Discount rates of capital was estimated at 10% per season (20% per year) and applied only to cash costs [15]. 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 then 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 [13]. 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 [16]. The values of the costs used are presented in Table 4.

Table 4. Values used for cost benefit analysis

Parameter	Value (USD)		
	Season 1	Season 2	Season 3
Price of Urea kg^{-1}	1.80	2.10	2.10
Transport of urea to the farm 100 kg^{-1}	1.75	1.75	1.75
Labor cost			
Baseline cost for urea application ha^{-1*}	1.37	1.37	1.37
Cost for application of additional fertilizer ha^{-1}¶	0.30	0.30	0.30
Baseline cost for calliandra application ha^{-1}†	350	350	350
Cutting and application of 10 t ha^{-1} maize stover	430	430	430
Price of maize kg^{-1}	0.32	0.40	0.35

** Cost of application of 10 kg ha^{-1} as urea. Includes cost of transport of fertilizer within the homestead.*
¶ Cost of application of fertilizer above or below the baseline rate of 10 kg ha^{-1} as urea Calculated at 0.2 % of the baseline cost per additional kg of fertilizer.
† Cost of application of 15 kg N ha^{-1}. Includes cost for collection and transport of materials within the homestead. Cost for application of rates above or below 15 kg N ha^{-1} was directly proportional to the quantity of material applied.

3. RESULTS AND DISCUSSION

3.1 Maize Grain Yields

The maize grain yields varied among the seasons (Table 5). The mean grain yields of the third season (3.4 t ha^{-1}) were higher than those of the second season (2.1 t ha^{-1}) but lower than those of the first season (3.7 t ha^{-1}). The variation in maize grain yields observed among the seasons is attributed mainly to the differences in rainfall. In the first season, the rainfall was adequate (>1000 mm) during the growing period of maize and the uptake of nutrients by the crop was thus not inhibited leading to high grain yields. In the second season, the rainfall was low and poorly distributed. The total rainfall amount was < 500 mm in this season with only 48 mm being received in November, when the crop was tasselling. Uptake of nutrients was therefore constrained by low available moisture in this season. The lower yields observed in the third season compared to the second season, despite the fact that both were long rainy seasons with adequate total rainfall, is attributed to the little rainfall (230 mm) received in June and July in the third season. This coincided with the tasselling period of maize and, therefore, led to a reduction in grain yield compared to the first season when rainfall was higher during the two months.

Table 5. Maize grain yields at Bukura

Treatment no	Organic material	N from organics (kg ha^{-1})	N from urea (kg ha^{-1})	Total N (kg ha^{-1})	Grain yield (t ha^{-1})		
					Season1	Season 2	Season 3
1	None (control)	0	0	0	2.6	1.1	1.9
2	Calliandra	75	0	75	3.8	2.0	3.2
3	Calliandra	60	15	75	4.1	1.9	3.6
4	Calliandra	45	30	75	4.7	2.9	4.2
5	Calliandra	30	45	75	5.4	2.7	4.6
6	Calliandra	15	60	75	3.8	2.4	4.2
7	Maize stover	75	0	75	2.0	1.6	2.1
8	Maize stover	60	15	75	3.0	1.8	2.4
9	Maize stover	45	30	75	2.7	1.6	2.9
10	Maize stover	30	45	75	3.9	2.2	3.4
11	Maize stover	15	60	75	4.5	1.9	4.0
12	None	0	75	75	4.3	2.5	4.5
	SED				0.58	0.36	0.51
	Cv%				5.9	8.0	5.9

Treatments with Calliandra when combined with urea tended to be the best performers across the seasons. For example, The highest increase in maize yields relative to the control in the first season (107%) and third season (142%) was with calliandra applied to provide 30 kg N ha^{-1} in combination with urea (45 kg N ha^{-1}) while in the second season, calliandra (45 N ha^{-1}) combined with urea (30 kg ha^{-1}) gave the highest increase (163%) in yields relative to the control. Maize significantly responded to calliandra when applied alone or urea alone in all the seasons but failed to respond to maize stover when applied alone or in combination with low rates of urea. In fact maize stover when combined with urea gave significant increases in maize yields only when the rates of urea in the combination were higher than the N from the maize stover i.e. 45 and 60 kg N ha^{-1}. In general, the maize yields in the maize stover treatments increased with increasing substitution of maize stover with urea in the combinations in the first and third seasons. However, there was no consistent pattern in the second season where the low moisture levels may have confounded the effects. The low yields obtained when maize stover was applied to supply N at higher rates is attributed to immobilization of N by the maize stover. The maize stover had a C:N ratio of 65 which is way above the minimum threshold of < 20 that is required for mineralization to occur. In addition, the stover was high in lignin and polyphenol content which are likely to have exacerbated the immobilization. The maize growing in these treatments therefore suffered N deficiency. Combining the maize stover with urea at high rates reduced the C:N ratio to lower than 20 and effected mineralization that overcame the N deficiency. Calliandra on the other hand had a high N content (3%) and low C:N ratio (15:1) hence would be expected to mineralize even without the addition of a readily soluble source of N e.g. urea if other factors were constant. However, due to its high polyphenol (14%) and lignin contents (25%) the rate of mineralization is likely to have been slowed down when applied alone without urea. According to [7] OMs with a polyphenol content of > 4% and lignin content of > 16% will immobilize N and have therefore to be supplemented with inorganic N fertilizers. Hence addition of urea even in modest amounts to calliandra was enough to overcome the deleterious effects of these compounds and enabled mineralization to occur at faster rates to provide enough N for the maize and therefore the high yields in the calliandra/urea combinations. The generally good response to urea when applied alone (75 kg N ha^{-1}) is to be expected since this site was N deficient and urea provided N in readily available form. However, the slight superiority of the treatments where urea was integrated with calliandra is attributed to synergistic effects often observed when appropriate organic and inorganic sources of nutrients are combined. For example, organic materials confer other advantages e.g. moisture retention, provision of micronutrients and alleviation of mineral toxicities [7, 14].

3.2 Economic Analysis

Total variable costs of using the OMs when applied alone were higher than using urea alone (Table 6). Maize stover applied alone (75 kg N ha^{-1}) had the highest added costs followed by calliandra when applied alone. The added 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.

Cost of labour form a major part of the total cost in the use of organic materials in western Kenya [14]. Labour forms more than half of the total variable costs of production when organic matter technologies are used. This is because the use of organic materials is labour intensive. Labour cost constituted 100% of the added costs (input+labour) when stover was applied alone and 42-94% of the added cost when it was integrated with inorganic N sources. Labour costs constituted 100% of the added costs when *Calliandra* was applied alone and 29-80% of the added cost when it was integrated with urea. Labour costs for inorganic N when not integrated with organic materials, were small and represented approximately 1% of the total added costs in all seasons.

In all the seasons the highest net benefits were obtained with *Calliandra* applied at 30 kg N ha^{-1} plus urea applied at 45 kg N ha^{-1} (Table 7). All treatments in which maize stover supplied 45 kg N ha^{-1} or more, had negative net financial benefits in all seasons mainly to the high labour costs and associated low yields due to N immobilization. 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 (Table 7). Net financial benefits were low in the second season 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 [17].

Table 6. Total variable costs (US dollars) associated with different treatments at Bukura

Treatment no.	Organic material	N from organics (kg ha^{-1})	N from urea (kg ha^{-1})	Total N (kg ha^{-1})	Season1	Season 2	Season 3
1	None	0	0	0	-	-	-
2	Calliandra	75	0	75	350	350	350
3	Calliandra	60	15	75	345	359	367
4	Calliandra	45	30	75	340	349	385
5	Calliandra	30	45	75	264	290	337
6	Calliandra	15	60	75	383	394	382
7	Maize stover	75	0	75	546	559	555
8	Maize stover	60	15	75	520	522	515
9	Maize stover	45	30	75	470	487	472
10	Maize stover	30	45	75	446	469	455
11	Maize stover	15	60	75	410	429	421
12	None	0	75	75	336	394	394

Table 7. Net financial benefits (US dollars) and benefit cost ratios associated with different treatments at Bukura

Treatment No.	Organic material	N/organics	N/ urea	Total N (kg ha^{-1})	Net benefits			Benefit cost ratio		
					Season1	Season2	Season3	Season1	Season2	Season3
1	None	0	0	0	-	-	-	-	-	-
2	Calliandra	75	0	75	110	44	71	0.31	0.13	0.20
3	Calliandra	60	15	75	-44	-9	181	-0.12	-0.02	0.49
4	Calliandra	45	30	75	116	444	344	0.34	1.27	0.89
5	Calliandra	30	45	75	227	502	471	0.59	1.73	1.40
6	Calliandra	15	60	75	16	156	330	0.06	0.40	0.86
7	Maize stover	75	0	75	-608	-494	-584	-1.11	-0.88	-1.05
8	Maize stover	60	15	75	-518	-521	-515	-0.10	-0.99	-1.00
9	Maize stover	45	30	75	-470	-486	-471	-1.00	-1.00	-0.99
10	Maize stover	30	45	75	163	5.7	30	0.36	0.01	0.06
11	Maize stover	15	60	75	2.9	-88	258	0.01	-0.21	0.61
12	None	0	75	75	16	190	470	0.05	0.48	1.19

The benefit cost ratios (BCRs) were low and varied between seasons and treatments. 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 [18]. However, Calliandra when applied at a rate of 30 kg ha^{-1} in combination urea at 45 kg ha^{-1} showed promise especially in the second and third seasons with BCRs of 1.78 and 1.40 respectively.

4. CONCLUSION

Maize yields varied with season and treatments. Treatments with Calliandra when combined with urea tended to be the best performers across the seasons. Despite the good agronomic performance by the calliandra treatments, it is unlikely that farmers would adopt its use as a source of nutrients for maize mainly because of the high labour costs associated with its use which led to low BCRs. Maize stover tended to depress yields when applied in large quantities likely due to N immobilization. This is likely the reason why farmers prefer to burn it. However, due to its importance in maintaining soil organic matter, it should be retained in the fields and urea applied at higher rates to overcome N immobilization where it is economically feasible. There is need, therefore, for the Kenya Government to reintroduce fertilizer subsidies which were scrapped in the 1990's. This study highlights the importance of economic analysis in agronomic studies. Practices that may appear agronomically effective may turn out to be economically unattractive hence hindering their adoption by farmers.

ACKNOWLEDGEMENTS

We are grateful to Mary Emong'ole for soil analyses and Samuel Kirui and Evans Tambwa for managing the field experiments. Financial support for this study was provided by the Kenya Forestry Research Institute (KEFRI).

COMPETING INTERESTS

Authors have declared that no competing interests exist

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Peer-review history:
The peer review history for this paper can be accessed here:
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