

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

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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 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.

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

69
70 **2. MATERIAL AND METHODS**
71 **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 western 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

82

83 2.2. Experimental layout and management

84 The experiment was laid out in a randomized complete block design with twelve treatments
85 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 OM's represent common alternatives to inorganic fertilizers on smallholder farms, but vary in their chemical characteristics (Table 3).

Table 2. The experimental treatments

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

99 Table 3. Selected chemical characteristics of the organic materials

Organic material	Parameter								
	%N	%P	%K	%Ca	%Mg	%C	% Polyphenol	%Lignin	C:N
<i>Calliandra</i>	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

100

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

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

119

120 2.3. Economic analysis

121 Cost and benefits associated with each treatment were compared using partial
 122 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
<u>Labor cost</u>			
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.

141 † Cost of application of 15 kg N ha⁻¹. Includes cost for collection and transport of materials within
142 the homestead. Cost for application of rates above or below 15 kg N ha⁻¹ was directly
143 proportional to the quantity of material applied.

144

145 **3. RESULTS AND DISCUSSION**

146 **3.1. Maize grain yields**

147 The maize grain yields varied among the seasons (Table 5). The mean grain yields of the third
148 season (3.4 t ha⁻¹) were higher than those of the second season (2.1 t ha⁻¹) but lower than those
149 of the first season (3.7 t ha⁻¹). The variation in maize grain yields observed among the seasons
150 is attributed mainly to the differences in rainfall. In the first season, the rainfall was adequate
151 (>1000 mm) during the growing period of maize and the uptake of nutrients by the crop was thus
152 not inhibited leading to high grain yields. In the second season, the rainfall was low and poorly
153 distributed. The total rainfall amount was < 500 mm in this season with only 48 mm being
154 received in November, when the crop was tasselling. Uptake of nutrients was therefore
155 constrained by low available moisture in this season. The lower yields observed in the third
156 season compared to the second season, despite that both were long rainy seasons with
157 adequate total rainfall, is attributed to the little rainfall (230 mm) received in June and July in the
158 third season. This coincided with the tasselling period of maize and, therefore, led to a reduction
159 in grain yield compared to the first season when rainfall was higher during the two months.

160 Treatments with Calliandra when combined with urea tended to be the best performers
161 across the seasons. For example, The highest increase in maize yields relative to the control in
162 the first (107%) season and third seasons (142%) was with calliandra applied to provide 30 kg
163 N ha⁻¹ in combination with urea (45 kg N ha⁻¹) while in the second season, calliandra (45 N ha⁻¹)
164 combined with urea (30 kg ha⁻¹) gave the highest increase (163%) in yields relative to the control.
165 Maize significantly responded to Calliandra when applied alone or urea alone in all the seasons
166 but failed to respond to maize stover when applied alone or in combination with low rates of urea.
167 In fact maize stover when combined with urea gave significant increases in maize yields only
168 when the rates of urea in the combination were higher than the N from the maize stover i.e. 45
169 and 60 kg N ha⁻¹. In general, the maize yields in the maize stover treatments increased with

170 increasing substitution of maize stover with urea in the combinations in the first and third season.
171 However, there was no consistent pattern in the second season where the low moisture levels
172 may have confounded the effects. The low yields obtained when maize stover was applied to
173 supply N at higher rates is attributed to immobilization of N by the maize stover. The maize
174 stover had a C:N ratio of 65 which is way above the minimum threshold of < 20 that is required
175 for mineralization to occur. In addition, the stover was high in lignin and polyphenol content which
176 are likely to have exacerbated the immobilization. The maize growing in these treatments
177 therefore suffered N deficiency. Combining the maize stover with urea at high rates reduced the
178 C:N ratio to lower than 20 and effected mineralization that overcame the N deficiency. Calliandra
179 on the other hand had a high N content (3%) and low C:N ratio (15:1) hence would be expected
180 to mineralize even without the addition of a readily soluble source of N e.g. urea if other factors
181 were constant. However, due to its high polyphenol (14%) and lignin contents (25%) the rate of
182 mineralization is likely to have been slowed down when applied alone without urea. According to
183 [7] OM with a polyphenol content of $> 4\%$ and lignin content of $> 16\%$ will immobilize N and
184 have therefore to be supplemented with inorganic N fertilizers. Hence addition of urea even in
185 modest amounts to calliandra was enough to overcome the deleterious effects of these
186 compounds and enabled mineralization to occur at faster rates to provide enough N for the maize
187 and therefore the high yields in the calliandra/urea combinations. The generally good response to
188 urea when applied alone (75 kg N ha^{-1}) is to be expected since this site was N deficient and urea
189 provided N in readily available form. However, the slight superiority of the treatments where urea
190 was integrated with calliandra is attributed to synergistic effects often observed when appropriate
191 organic and inorganic sources of nutrients are combined. For example, organic materials confer
192 other advantages e.g. moisture retention, provision of micronutrients and alleviation of mineral
193 toxicities [7, 14].

194 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

195 3.2. Economic analysis

196 Total variable costs of using the OM_s when applied alone were higher than using urea
197 alone (Table 6). Maize stover applied alone (75 kg N ha⁻¹) had the highest added costs followed
198 by calliandra when applied alone. The added costs for integrating the inorganic and organic
199 sources of nutrients were in between the extremes. The higher costs for the OM treatments
200 resulted mainly from the high labour cost associated with their use because of the large amounts
201 that had to be harvested and applied. For example, approximately 8.33 t ha⁻¹ of fresh *Calliandra*
202 biomass was required to supply 75 kg N per ha⁻¹. At the practical farming level, the labour costs
203 for harvesting, transporting and incorporating it were therefore quite high. These costs are likely
204 to further increase if many farmers were to adopt the *Calliandra* biomass transfer technology as
205 the amount of *Calliandra* available will not be sufficient to meet the demand. Added costs for the
206 use of maize stover were also high mainly because of the low N (0.65 %) content of the stover
207 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
208 stover was applied.

209 Cost of labour form a major part of the total cost in the use of organic materials in
210 western Kenya [14]. Labour forms more than half of the total variable costs of production when
211 organic matter technologies are used. This is because the use of organic materials is labour
212 intensive. Labour cost constituted 100% of the added costs (input+labour) when stover was
213 applied alone and 42-94% of the added cost when it was integrated with inorganic N sources.
214 Labour costs constituted 100% of the added costs when *Calliandra* was applied alone and 29-
215 80% of the added cost when it was integrated with urea. Labour costs for inorganic N when not
216 integrated with organic materials, were small and represented approximately 1% of the total
217 added costs in all seasons.

218 In all the seasons the highest net benefits were obtained with *Calliandra* applied at 30 kg
219 N ha⁻¹ plus urea applied at 45 kg N ha⁻¹ (Table 7). All treatments in which maize stover supplied
220 45 kg N ha⁻¹ or more, had negative net financial benefits in all seasons mainly to the high labour
221 costs and associated low yields due to N immobilization. However, when the maize stover was
222 used to provide only 30 kg N ha⁻¹ or less, the financial benefits were generally positive indicating

223 that the increase in yields as a result of increasing rate of urea in the combination was enough to
224 offset the added costs associated with the integration (Table 7). Net financial benefits were low
225 in the second season mainly due to low grain yields realized in these seasons. Adequate extra
226 yield that would offset the high costs of using organic residues and allow subsequent economic
227 benefit was hardly achieved under the prevailing low rainfall conditions of the second season.
228 Similar season specific responses have been reported by others [17].

229 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

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

Treat.	Organic material	N/ organics	N/ urea	Total N (kg ha ⁻¹)	Season 1	Season 2	Season 3	Season 1	Season 2	Season 3
Net benefits								Benefit cost ratio		
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.

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COMPETING INTERESTS

Authors have declared that no competing interests exist

AUTHORS' CONTRIBUTIONS

R. Nyambati designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. P.A. Opala managed the analyses of the study and the literature searches. Both authors read and approved the final manuscript.

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