

Beneficial Nutrient Management Practices for Improving Maize (*Zea mays*) Yield in a Tropical Entisol

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ABSTRACT: Beneficial nutrient management practices could increase maize yield via improving soil fertility. A study was conducted in the mid country wet zone of Sri Lanka (WM2b) on Typic Troprothents aiming to formulate a site specific fertilizer (SF) recommendation and to identify beneficial organic soil amendments (OA) to improve the fertility and productivity of soils for maize cultivation. The SF recommendation was developed using modified missing element technique. Incubated mixture of cattle manure and sawdust at 2:1 wet weight basis (CS-i) and biochar (BC) derived from sawdust were selected as OAs. Four treatments, (i) un-amended control (S), (ii) soil amended with SF (SSF), (iii) cattle manure-sawdust CS-i (2.2 Mg ha⁻¹) with SF (CSi+SF) and (iv) biochar (1.1 Mg ha⁻¹) with SF (BC+SF) were tested in the field for two consecutive growing seasons (Yala 2013 and Maha 2013/14) for maize. According to missing element technique, soil was deficient in K, Mg, P and Zn nutrients and resulted in 38%, 35%, 27% and 24% relative dry-matter reductions, respectively. Addition of OA+SF significantly improved soil organic carbon content compared to SSF. Green cob yield ranged from 7.9 to 16.5 Mg ha⁻¹ in Yala and 5.4 to 12.4 Mg ha⁻¹ in Maha increasing yield significantly in CS-i+SF, BC+SF and SSF over the un-amended control in both seasons. Soil fertility and maize yield were sustained or improved under combined application of site specific fertilizer and organic amendments. Moreover, cut down of K fertilizer is possible with application of BC and CS-i OAs. Hence, SF recommendation along with biochar or cattle manure-sawdust mixture OAs is a beneficial nutrient management practice for cultivating maize.

Keywords: biochar, cattle manure, sawdust, site specific fertilizer recommendation, soil fertility

INTRODUCTION

Depletion of soil organic matter (SOM) and plant nutrients lead to reduction in soil fertility and productivity. This problematic situation is aggravated by continuous cultivation coupled with the mismanagement of nutrient sources, especially mineral fertilizers resulting in imbalanced soil nutrient status. Balanced crop nutrition through a site-specific approach may help to overcome this problem and improve crop yields as nutrient related problems could be site specific (Haefele and Wopereis, 2005). Optimization of crop production and minimization of soil nutrient losses are favorable outcomes of practicing site specific fertilizer management (Dobermann *et al.*, 2002). A systematic approach to develop site

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specific fertilizer recommendation by means of soil analyses, nutrient fixation studies and greenhouse experiments with missing element technique was outlined by Portch and Hunter (2002), and has been validated and tested in different countries including Sri Lanka (Amarasekara *et al.*, 2007; Pasuquin *et al.*, 2010; Kumaragamage and Indraratne, 2011; Herath *et al.*, 2013).

Organic amendments (OAs) affect SOM pool and influence nutrient availability. Due to their high decomposition rates, animal and crop residues are required in large quantities with repeated additions to significantly improve SOM pool (Hai *et al.*, 2010). Commonly used OAs in Sri Lanka such as animal manure and rice straw, are not available in all places and during all seasons. Thus, finding alternative OAs capable of prolonged replenishment of SOM reserves is important. High C/N materials like wood waste and biochar could be such alternative OAs. But wood based materials are not desirable sources of organic matter due to low levels of readily available nutrients (Halim and Baroudy, 2014), and high C/N ratio, which causes soil N immobilization (Miller *et al.*, 2010).

Decomposable carbonaceous materials such as sawdust can be composted or (Miller *et al.*, 2010) incubated with N rich organic materials or with N fertilizers to reduce C/N ratio to decrease the inclination to immobilize soil N and convert it to high quality organic material. Even though biochar (pyrolyzed biomass) is a carbonaceous material with C content of 70-80% (Lehmann and Rondon, 2006) evidence exists of the positive effects of its application to soil increasing plant nutrient uptake and crop yield (Lehmann and Rondon, 2006).

Incorporation of organic materials, which can persist in soil for a long time, in addition to application of balanced quantities of mineral fertilizers is a beneficial nutrient management practice (BMP) which can help sustaining soil fertility and productivity. Very few studies have been done in order to observe the effects of wood wastes such as sawdust and biochar on soil fertility and productivity in the tropics. Therefore, a study was conducted with the objectives of (a) to identify soil fertility constraints of a selected land and develop a site specific fertilizer recommendation and (b) to evaluate the suitability of two sawdust based soil amendments (sawdust-cattle manure mixture and biochar) for improvement of soil fertility and productivity.

MATERIALS AND METHODS

Study site, soil sampling and experimental design

Soil samples were collected from an upland crop field at Peradeniya located in the mid country wet zone (WM2b). The soil belongs to the order of Typic Troporthents (Mapa *et al.*, 1999). Soil samples were collected at the beginning and at the end of each season (*Yala 2013* and *Maha 2013/14*) by stratified random sampling method, and mixed to obtain a representative composite sample. Soil was air-dried and sieved through a 2 mm sieve and used for initial soil analyses, laboratory incubations and greenhouse experiments. Organic soil amendments were prepared and characterized. A site specific fertilizer recommendation (SF) was formulated based on initial soil nutrient levels, nutrient fixation capacities of soil, and a greenhouse experiment. The effect of SF and OAs on soil fertility and productivity were tested in a field experiment.

Soil analyses

Soil texture was determined by pipette method (Gee and Bauder, 2002). Soil pH and EC were measured in soil: distilled water suspension (1:2.5) and total organic carbon (TOC) content was determined following modified Walkley and Black method (Nelson and Sommers, 1996). Cation exchange capacity was analysed using ammonium as index ion at pH 7 (Summer and Miller, 1996). Potentially mineralizable N (PMN) was determined by anaerobic incubation technique (Keeney and Nelson, 1982).

Preparation of organic soil amendments and analyses

Cattle manure was mixed with sawdust (*Alstonia macrophylla*) at 2:1 ratio (wet weight basis) and incubated (CS-i) at room temperature under aerobic condition for two months to facilitate partial decomposition of the material through the activity of mesophilic microorganisms. Biochar (BC) was produced from sawdust (*A. macrophylla*) at the Rubber Research Institute of Sri Lanka, by slow pyrolysis method as described by Dharmakeerthi *et al.* (2012).

The pH and EC of OAs were measured in material: water suspension of 1:5. Cation exchange capacity (CEC) was measured using ammonium as index ion at pH 7. Total fixed C was measured by loss on ignition method (Enders *et al.*, 2012) and total N was determined using acid digestion followed by Kjeldhal distillation. All the analyses were performed following standard laboratory protocol. C/N was calculated using total C and N determinations.

Formulation of a site specific fertilizer (SF) recommendation

Available nutrients (NH_4^+ - N, available P, S, Zn and exchangeable K, Ca, Mg) were extracted as described by Portch and Hunter (2002) using three different multi-element extraction methods. Ammonium-N was determined by salicylate colourimetric method (Markus *et al.*, 1985) and the colour intensity was measured at 660 nm using UV-Visible spectrophotometer. Extracted K was measured by flame emission spectrophotometer and Ca, Mg and Zn were determined using atomic absorption spectrophotometer. Phosphorous was determined by molybdenum blue colour method, and concentration of S was determined by turbidimetric method.

Nutrient fixation capacities of soil were determined using a series of experiments (Portch and Hunter, 2002). The quantity of P and K to be added was determined from a fixation curve plotted between the amounts of nutrient extracted against the amounts of nutrient added to the soil. Amount of deficient nutrient to be added was calculated based on “optimum” levels (Table 1) as suggested by Portch and Hunter (2002). The status of individual nutrients was tested according to modified missing element technique (Portch and Hunter, 2002) using maize (*Zea mays*) (Hybrid variety – *Sampath*) as test crop in a greenhouse pot experiment arranged in a complete randomized block design with four replicates. Treatments were the optimum (OP) and individual treatments missing each N, P, K, Ca, Mg and Zn from the OP as described previously (Portch and Hunter, 2002). Relative dry matter yields (biomass) of one month old seedlings were determined as a percentage by the following formula.

$$\text{Relative yield} = \frac{\text{Dry matter yield of the treatment}}{\text{Dry matter yield of the optimum treatment}} \times 100$$

The SF recommendation was formulated based on the greenhouse study, initial nutrient concentrations in soil and present recommendation for maize developed by the Department of Agriculture (DOA, 2013).

Effect of organic soil amendments on soil fertility parameters, maize growth and yield under field condition

A field experiment was conducted using a randomized complete block design with four replicates. Treatments were: un-amended control (S), soil mixed with mineral fertilizer (SSF), soil mixed with cattle manure- sawdust mixture and mineral fertilizer (CS-i+SF) and soil mixed with biochar and mineral fertilizer (BC+SF). Biochar was added at a rate of 1.1 Mg ha⁻¹ and CS-i at 2.2 Mg ha⁻¹ in dry weight basis. The rates of BC and CS-i were decided based on laboratory and greenhouse experiments in a previous study (Mariaselvam *et al.*, 2015). In treatments that received OAs mineral fertilizers were added to supply matching nutrients levels as of SSF. Maize (variety *Sampath*) was grown in 3 m x 3 m plots (60 cm x 30 cm spacing) under irrigated condition. One plant per hill was maintained until harvest of green cobs at 85 days for *Yala* and *Maha* 2013. Plant height at 50% flowering stage was measured and oven dry weight of plant shoots and roots were determined. Number of seeds per cob, fresh weight of corn ear, fresh weight of corn cob, and length and diameter of cob were determined as yield quality parameters.

Four soil samples were collected per plot from 0-15 cm depth at the end of each season to compose a representative sample of the plot. Available N and PMN were analysed on fresh soil and other soil fertility parameters (pH, EC, CEC, TOC) were analysed on air-dried and sieved (2 mm) soil.

Statistical analyses

Statistical analysis was performed using SAS program (Version 9.1). Analysis of variance (ANOVA) was used to determine the statistical significance of treatment effects. Duncan's multiple-range test was used to compare treatment means. The 0.05 probability level was regarded as statistically significant.

RESULTS AND DISCUSSION

Initial soil characteristics

Texture of soil was sandy clay loam with 50.7 ± 0.8 % sand, 23.8 ± 0.3 % silt and 25.6 ± 0.6 % clay. Initially the organic matter content (1.7 % ± 0.07) was in the range usually observed in the wet zone soils of Sri Lanka (Kumaragamage *et al.*, 1999). Soil was slightly acidic (pH of 6.1 ± 0.16) with a moderate CEC (16 ± 2.30 cmol₍₊₎ kg⁻¹). Electrical conductivity (EC) was low (1.21 ± 0.1 dSm⁻¹) indicating non-saline status.

Formulation of site specific fertilizer recommendation

Considering the optimum soil nutrient levels expected, the soil used in the study was deficient in N, P, K, Ca, Mg and Zn (Table 1). The observation is in conformity with previous studies conducted in Sri Lanka (Nagarajah *et al.*, 1983, Kumaragamage and Indraratne 2011). High P and K fixing capacities were reported previously for a number of soils in Sri Lanka (Withana and Kumaragamage 1993; Kumaragamage and Indraratne 2011). Nutrient fixation capacity is influenced by SOM and clay mineralogy in soil (Indraratne and Thilakarathne, 2009). Both P and K fixation were observed for the soil used in present study. The amount of each nutrient to be added to match the optimum nutrient content was calculated considering the nutrient availability and fixation capacities of soil (Table 1). Accordingly, in missing-element technique the optimum treatment, which received the nutrients at the calculated levels, gave the highest yield (Table 2). A significant reduction of dry matter yield was observed when each K, Mg, P and Zn was not applied (38 %, 35 %, 27 % and 24 % yield reduction, respectively).

Table 1. Optimum nutrient concentration proposed by Portch and Hunter (2002), available nutrient concentrations in studied soil and amount of each nutrient to be added for the optimum treatment

Nutrient	Optimum mg kg ⁻¹	Available (mean±standard deviation) mg kg ⁻¹	Amount of nutrient to be added* mg kg ⁻¹
NH ₄ -N	100	2.8 (±0.05)	97.0
P	60	31.0 (±0.02)	43.0
K	196	102.0 (±0.10)	145.0
SO ₄ ²⁻ -S	40	43.0 (±0.01)	NA
Ca	1202	441.0 (±0.10)	761.0
Mg	304	223.0 (±0.20)	81.0
Zn	6	1.6 (±0.02)	4.4

*calculated based on available nutrient content and the nutrient fixation capacity of the soil (Portch and Hunter, 2002). NA - not applicable.

Table 2. Mean dry matter yield and relative yield of 30 days old maize seedlings for the tested treatments in the greenhouse experiment

Treatment	Mean Dry matter yield (g plant ⁻¹)	Relative yield %
Optimum	1.59 ^a	100
minus N	1.48 ^{ab}	93
minus P	1.15 ^{bcd}	73
minus K	0.99 ^d	62
minus Ca	1.42 ^{abc}	89
minus Mg	1.04 ^{cd}	65
minus Zn	1.21 ^{abcd}	76

* means followed by the same letter in a given column are not significantly different ($p < 0.05$)

In the present study, the site specific fertilizer recommendation for maize was formulated considering data from the greenhouse experiment with missing element technique, soil analyses, and present fertilizer recommendation for maize developed by the Department of Agriculture (DOA, 2013). The DOA recommendation include only urea, triple super phosphate (TSP) and muriate of potash (MOP) at 325, 100 and 50 kg ha⁻¹, as the N, P and K sources respectively. Kumaragamage and Indraratne, (2011) reported “optimum” concentrations of some nutrients need to be adjusted before using them in a fertilizer recommendation programme. Minus N did not show a significant yield difference compared to “optimum” treatment. As crop specific N requirement was not evaluated in the missing element technique, DOA recommendation was considered for N. Potassium fixation was observed in the soil and exclusion of K in the greenhouse study caused a significant dry matter yield reduction. Considering the crop specific requirement (generally 125 kg ha⁻¹ of K in soil) and economic feasibility of using K fertilizer it was decided to use MOP at the rate of 100 kg ha⁻¹ in the site-specific recommendation. The absence of Mg reduced the dry matter yield markedly. Thus, dolomite was added to fulfill Mg requirement. But the dolomite quantity was adjusted to prevent soil becoming alkaline as the pH of soil was only slightly acidic (pH=6). The full benefit of adding major nutrients N, P and K can be received only if deficiencies of secondary and micronutrients are rectified (Amarasekara *et al.*, 2007). Therefore, Zn was supplied as Zn sulfate.

Organic soil amendments on soil fertility

Both OAs differed in their characteristics (Table 3). The pH of OAs were in alkaline range. Biochar produced from woody feedstock reported to have pH in the range of 4 - 9 (Enders *et al.*, 2012). Most wood products have pH ranging from 3.5 - 7 depending on the tree species (Barney and Colt, 1991). Biochar had higher fixed C and consequently higher C/N ratio compared to CS-i. Fixed C of biochar used in the present study is within the range reported in literature for biochar derived from Corn, Hazelnut, Oak and Pine, which varied from 60% to 91% (Enders *et al.*, 2012). Potassium was higher in CS-i compared to BC. Considering K levels of OAs the amounts of fertilizers added along with OAs were adjusted so that all three treatments (SSF, CS-i+SF and BC+SF) receive the same level of nutrients (Table 4). Thus, application of BC and CS-i reduced MOP application by 25% and 50%, respectively. As both OAs were low in available N and P (Table 3), the amounts of N and P fertilizers were not adjusted and thus, were the same for all three treatments (Table 4).

Table 3. Characteristics of the organic soil amendments cattle manure- sawdust (incubated) (CS-i) and biochar (BC) (dry weight basis)

Parameter	BC	CS-i
pH (1:2.5)	8.7	7.8
Electrical conductivity (dS m ⁻¹)	1.4	3.4
Cation exchange capacity (cmol _c kg ⁻¹)	46.0	NA
Fixed C (C %)	86.0	62.0
Total (N %)	0.8	1.2
C/N ratio	108.0	52.0
N (mg kg ⁻¹)	57.0	37.0
P (mg kg ⁻¹)	11.0	15.0
K (mg kg ⁻¹)	1736.0	2456.0

NA- not analyzed

Table 4. The fertilizer recommendation of Department of Agriculture (DOA) (2013) for maize and the amount of mineral fertilizers added under each treatment (SSF, BC+SF, CS-i+SF) in the field experiment

Fertilizer	DOA (kg ha ⁻¹)	SSF (kg ha ⁻¹)	BC+SF (kg ha ⁻¹)	CS-i+SF (kg ha ⁻¹)
Urea	325	325	325	325
TSP	100	100	100	100
MOP	50	100	75	50
Zn Sulfate	-	5	5	5
Dolomite	-	73	73	73

SSF-soil+fertilizer, CS-i+SF cattle manure+sawdust (incubated) +mineral fertilizer, BC+SF-biochar+mineral fertilizer, TSP- Triple Super Phosphate, MOP- Muriate of Potash

Significant differences in soil fertility parameters, viz. TOC, PMN and EC across treatments were observed in both seasons (Table 5). Addition of BC and CS-i significantly increased TOC content by 24% than the un-amended control treatment (S). In a previous study application of red pine sawdust increased soil OM by 21% compared to the control (Koll *et al.*, 2010). Novak *et al.* (2009) observed that addition of 1% and 2% of biochar significantly increased soil organic C content compared to the control.

Table 5. Soil fertility parameters before cultivating maize (*Zea mays*) in Yala-2013 (initial), after harvesting the crop in Yala 2013 (Yala) and Maha 2013/14 (Maha) growing seasons

Season	Treatment	TOC (%)	PMN (ug N g ⁻¹ soil week ⁻¹)	pH (1:2.5)	EC (dS m ⁻¹) (*10 ⁻¹)	CEC (cmol ₊ kg ⁻¹)
Initial		0.98	4.63	6.1	1.21	16
Yala	S	0.98 ^c	13.7 ^b	5.8 ^a	1.24 ^a	16 ^a
	SSF	1.08 ^b	8.2 ^d	6.0 ^a	1.16 ^b	18 ^a
	CS-i+SF	1.22 ^a	11.9 ^c	5.1 ^b	1.19 ^{ab}	16 ^a
	BC+SF	1.22 ^a	14.2 ^a	4.9 ^b	0.93 ^c	18 ^a
Maha	S	0.93 ^C	9.2 ^C	5.0 ^A	0.98 ^C	16 ^A
	SSF	1.10 ^B	21.1 ^B	5.1 ^A	1.59 ^B	15 ^B
	CS-i+SF	1.16 ^A	21.0 ^B	5.0 ^A	1.91 ^A	14 ^{BC}
	BC+SF	1.16 ^A	26.5 ^A	4.9 ^A	1.86 ^A	14 ^{BC}

#S-un-amended control, SSF-soil+fertilizer, CS-i+SF cattle manure+sawdust (incubated)+mineral fertilizer, BC+SF-biochar+mineral fertilizer. TOC-total soil organic carbon, PMN-potentially mineralizable N, EC-electrical conductivity, CEC-cation exchange capacity. Means with similar letters in a given column for each season are not significantly different. (P<0.05, n=4).

Labiality of organic N in soil is reflected by PMN, which is largely determined by soil OM quality and the activity of microorganisms, with higher values indicating a larger labile pool and vice versa. PMN is considered an important soil biological fertility parameter (Mijangos *et al.*, 2006). In the present study the presence of plants enhanced PMN in soil as expected, which is indicated by higher PMN values at the end of growing season compared to the initial values (Table 5). This can be attributed to rhizo-deposition occur with the presence of plants (Table 5). PMN was significantly enhanced with BC addition in both seasons

reflecting the impact of biochar on N dynamics in soil. Since BC is not a good source of labile N, enhanced PMN may be due to enhancement of microbial activity via supplying labile C and modifying microbial habitats. It has been shown that slow pyrolysis biochar addition results in net soil N mineralization (Bruun *et al.*, 2012). The effect of BC on existing SOM decomposition requires further investigation. In contrast to biochar, CS-i reduced PMN significantly lowering it than PMN in un-amended control in the first season, which indicates temporary immobilization of N. Miller *et al.* (2010) attributed the lower soil mineralizable N in composted manure containing wood chips to the more stable and resistant C present in the material. The changes in PMN with BC and CS-i indicate the variability in the effect of two different carbonaceous materials prepared from sawdust on N availability in soil.

Table 6. Plant growth parameters and yield of maize (*Zea mays*) during Yala (2013) and Maha (2013/14)

Season	Treatment	Height at 50% flowering (cm)	Root dry weight (g)	Shoot dry weight (g)	Yield (Mg ha ⁻¹)
Green cob stage					
Yala	S	126 ^d	16 ^c	152 ^b	7.98 ^b
	SSF	163 ^b	26 ^b	306 ^a	15.51 ^a
	CS-i+SF	169 ^a	32 ^b	319 ^a	16.51 ^a
	BC+SF	156 ^c	43 ^a	291 ^a	15.10 ^a
Maha	S	88 ^D	7 ^C	61 ^C	5.36 ^C
	SSF	132 ^B	20 ^B	125 ^B	10.30 ^B
	CS-i+SF	119 ^C	35 ^A	169 ^A	12.40 ^A
	BC+SF	143 ^A	24 ^{AB}	168 ^A	10.49 ^B

#S-un-amended control, SSF-soil+fertilizer, CS-i+SF cattle manure+sawdust (incubated)+mineral fertilizer, BC+SF-biochar+mineral fertilizer. Means with similar letters in a given column for each season are not significantly different. (P<0.05, n=4).

Organic soil amendments on crop growth and yield

Significant differences were observed in plant growth parameters across treatments at 50% flowering stage (Table 6). Both root and shoot dry weights were significantly increased in BC+SF, CS-i+SF and SSF treatments in both seasons. When soil was amended SSF, shoot and root biomass were notably reduced compared to plants grown with both OA and SF.

In the first season (*Yala*), yield was comparable among SSF, CS-i+SF and BC+SF treatments. But in the following season, CS-i+SF increased the yield significantly compared to other treatments. This may be due to improved soil properties over the two growing seasons. Haynes and Swift (1986) found that pine bark amendments improved plant growth and yield of blueberry plants due to modification of the soil physical environment rather than soil chemistry. Kimetu *et al.* (2008) reported doubling of cumulative maize yield after three repeated biochar applications of 7 Mg ha⁻¹ over 2 years. The low amount (1.1 Mg ha⁻¹) and shorter time period of biochar addition in this study might be the reason for not observing a higher yield in BC+SF compared to SSF. Similar observations were reported by Chaturika *et al.* (2014) with these two amendments. Yield quality was improved significantly by SSF,

CS-i+SF and BC+SF in both seasons compared to the control as indicated by the yield quality parameters (Table 7). Chivenge *et al.* (2011) reported that mean yield responses of *Zea mays* for addition of N fertilizers, and combination of organic residue and N fertilizer was 84% and 114% respectively, over the control. The lower yield observed in *Maha* compared to *Yala* can be attributed to the severe dry weather experienced during *Maha*.

Table 7. Yield parameters of maize (*Zea mays*) at green cob stage in the field during (*Yala 2013 and Maha 2013*)

Season	Treatment	No. of seeds per cob	Ear fresh weight (g)	Cob fresh weight (g)	Cob length (cm)	Cob diameter (cm)
Yala	S	328 ^b	150 ^c	97 ^c	17 ^c	12 ^b
	SSF	531 ^a	386 ^a	271 ^a	22 ^a	14 ^a
	CS-i+SF	547 ^a	362 ^{ab}	233 ^b	21 ^b	14 ^a
	BC+SF	546 ^a	312 ^b	213 ^b	21 ^b	14 ^a
Maha	S	266 ^C	120 ^C	81 ^C	17 ^C	11 ^B
	SSF	402 ^B	185 ^B	142 ^B	18 ^{BC}	12 ^A
	CS-i+SF	466 ^A	279 ^A	176 ^A	21 ^A	12 ^A
	BC+SF	427 ^{AB}	234 ^B	152 ^{AB}	19 ^B	12 ^A

#S-un-amended control, SSF-soil+fertilizer, CS-i+SF cattle manure+sawdust (incubated)+mineral fertilizer, BC+SF-biochar+mineral fertilizer. Means with similar letters in a given column for each season are not significantly different. ($P < 0.05$, $n=4$).

CONCLUSIONS

Increment in dry matter yield by supplying deficient nutrients to soil indicated the importance of soil analysis in formulating site specific fertilizer recommendations. The two OAs used in the present study can be considered as carbonaceous material with high C/N ratio (108 and 52) but did not negatively affect soil fertility, plant growth or yield when applied with mineral fertilizers. Addition of BC and CS-i with fertilizers to supplement site specific nutrient requirement sustained or enhanced the yield of maize compared to yield under mineral fertilizers alone. Moreover, with BC and CS-i application it is possible to cut down K fertilizer (MOP) application by 25% and 50 % respectively, for maize in the study area. Therefore, incubated cattle manure-sawdust mixture and biochar produced from sawdust of *Alstonia macrophylla* are potential OAs to be applied with fertilizers at site specific recommendation rates in beneficial nutrient management to improve soil fertility and productivity.

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