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Full Length Research Paper

Organic materials quality assessment by nutrient recovery, mineral fertilizer equivalency and maize (*Zea mays* L.) allometry

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In Sub-Saharan African countries crop production and productivity is primarily limited by soil fertility decline. In view of this, organic materials can be used as fertilizer source. However, little basic information is available on the quality of locally available organic materials and how to synchronize nutrient release with plant nutrient requirement and growth stages. To this effect, locally available organic materials such as residues of soybean (SB), cow pea (CP), haricot bean (HB), chick pea (CHP), maize, (M) and farmyard manure (FYM) were evaluated along with different inorganic fertilizers (Yaramila (YM) and Urea + Di-ammonium Phosphate (UrDp) were applied to soil samples to grow a maize variety-Gibe 2 as test crop. The maize allometric parameters, nutrient ratios (NRs), nutrient recovery (NRy) and mineral fertilizer equivalency (MFE) were used to assess the mineral fertilizer value (MFV) of organic materials. MFE of organic materials was estimated as the available mineral N and P out of the fraction of total nitrogen and phosphorous applied relative to chemical fertilizers supply. The results revealed that maize allometry, NRy and MFE were significantly ($p<0.05$) influenced by fertilizer sources. Organic materials amendment resulted in poor maize allometry, low nutrient uptake and recovery perhaps due to their slow release of nutrients and microbial immobilization of nutrients. Interestingly, MFE of organic materials amended ranged from -201% with CHP to 63% with FYM, reflecting that extensive variation exist in terms of their MFV. This portrays that CHP residue is the poorest quality that displayed highest immobilization, and about 200% soil nutrient deficit, while FYM is the highest quality material that exhibited net mineralization and contributes 63% of the mineral fertilizer value of YM. The results suggest that the allometric parameters, NRy and MFE are the best methods to assess the MFV of organic materials for crop production under tropical soil.

Key words: allometry, organic materials, mineral fertilizer equivalency, mineral fertilizer value, nutrient ratios.

INTRODUCTION

Crop production in smallholder farming systems of Sub-Saharan Africa including Ethiopia is often under nutrient limited conditions. Many factors are responsible for this. Few crop residues often retained on farmers' field due to its competitive use for livestock feed, energy, cash source, construction material and fertilizer sources. On the other hand, given the poor economic capacity of smallholder farmers, the synthetic (chemical) fertilizers use for crop production is still at inadequate rates. Despite these facts, the main source of nutrients under such system is, therefore the decomposition of crop residues and animal manures. The main challenges of use of organic materials as fertilizer sources are the synchronization of nutrient release with crop growth requirements. Organic resources contain slow releasing nutrients and also have advantages of building soil organic matter. Organic resources enhance soil health through contributing carbon for cell building and energy source for soil microorganisms, nevertheless, the contribution of different organic materials as fertilizer source has not been carefully examined and quantified. This necessitates the detailed assessment of the mineral fertilizer value of on-farm available organic materials on a short term basis as compared to the commonly used chemical fertilizers.

Decomposition and nutrient release of organic materials are often assessed by microcosms under controlled laboratory condition (Khalil, 2005; Abera et al., 2012a), litterbag experiments (Coppens et al., 2007; Abera et al., 2013), or can be based on crop growth performance and nutrient concentrations in the plant biomass as a result of nutrient release due to decomposition of organic materials (Seo & Lee 2008; Abera et al., 2012b). Other studies rapidly examined the nutrient contents of organic materials using magnetic resonance spectrophotometer (Shepherd et al., 2003). Some of these techniques require high tech facilities and well qualified laboratory technicians, which are often limited in developing countries.

Since measuring N and P concentration is simple and cheap, it has been used as alternative to fertilizer studies by ecologist as a tool to assess vegetation's nutrient limitation (Koerselman & Meuleman, 1996; Güsewell, 2004). Nutrient ratios between N, P and K in plant tissues have also been used to identify balance of nutrients and nutrient limitations by employing fertilizer experiment itself (Sadras, 2006; Verloop et al., 2010; Lu et al., 2012). Accordingly, the nutrient ratio of plant tissue is supposed to be simple and cost-effective tool for assessing the nutrient availability in terrestrial ecosystems (Tessier & Raynal, 2003; Güsewell, 2004). It was suggested that N:P < 10 and N:K < 2.1 indicate N limitation, while N:P > 20 indicates P limitation, and K:P > 3.4 indicates K sufficiency in terrestrial ecosystem (Gong et al., 2011). Most of these optimum ranges of nutrient ratios have been investigated through chemical fertilizer experiments. It is essential to note that N:P ratios are the reflection of soil N and P availability. Moreover, most of the previous studies utilized nutrient ratios of young leaf, grasslands, forest trees and natural vegetations. There has been limited quantitative of information with food crops, except few recent works with amendment of organic fertilizers (Seo & Lee, 2008; Abera et al., 2012b).

Our previous laboratory incubation study showed that soils amended with quality legume residue (pigeon pea) resulted in net N mineralization, while poor quality legume residue (haricot bean) displayed net nitrogen immobilization (Abera et al., 2012a). A follow up greenhouse pot experiment with pigeon pea residue amendment improved maize allometric parameters due to its high nutrient assimilation, whereas haricot bean and maize residues application resulted in decrease of maize allometric parameters due to net N immobilization (Abera et al., 2012b). These previous studies conducted both incubation and greenhouse pot experiments involved a few types of crop residues that were assessed based on biomass production and nutrient concentration which were sampled once, at 90 days after planting. Though the benefits of animal manure as fertilizer sources have been well documented elsewhere, it has never been well studied in our condition. Moreover, comparative investigations of organic materials, crop residues and manure mineral fertilizer value as compared to inorganic fertilizers were also lacking. Indeed, in the present study we included more organic materials and sampling stages to elucidate their mineral fertilizer value. Therefore, the objective of the present study was to evaluate the mineral fertilizer value of organic materials by employing simple and cost effective methods such as allometric parameters, nutrient ratios, nutrient recovery and mineral fertilizer equivalency at 30, 60 and 90 days of sampling stages under greenhouse pot experiment condition.

MATERIALS AND METHODS

Collection and preparation of soil samples and organic materials

Soil samples were collected from 0-30 cm depth of the Research and Farm Center of Hawassa University, Ethiopia. Soil sampling site is situated 7°45′ N and 38° 38′ E, at the elevation of 1708 m a.s.l. The soil samples collected were mixed and homogenized to form uniform composite. The objects such as visible plant parts, large soil aggregates and stones were manually removed to achieve a fine seed bed. The soil particles proportion was 46, 28, and 26% of sand, silt and clay, respectively. The soil pH was 6.8 (H_2O), while its EC was 0.11 (ds/m). It held 1.6% organic C, 0.09% total N, 46.3 ppm available P, and 34.0 ppm available S. The soil also held 19.0 CEC, 1.9 K, 10.8 Ca, 2.8 Mg and 0.16 Na all in (cemol(+)/kg soil). It also contained of 0.95 Cu, 25.0 Fe, 27.5 Mn, 5.0 Zn and 1.8 B all in (ppm) and 2.1 CaCO3 (%).

Residues of soybean (SB, *Glycine max*), cow pea (CP, *Vigna unguiculata)*, haricot bean (HB, *Phaseolus vulgaris* L), chick pea (CHP, *Cicer arietinum*) and maize (M, *Zea mays* L) were collected at full physiological maturity. Except roots, most of the plant parts (leaves, stems, petioles, pods without seed, husks and stems) were included as plant residue. Prior to application to pots, the residues were first air dried, subsequently oven dried (72 °C for 48 h) and then ground with Thomas-Wiley laboratory Mill Model 4 (http://www.thomassci.com) to pass 1 mm size sieve (Abera et al., 2012b). Farmyard manure was collected from the Research and Farm Center of Hawassa University and then partially decomposed in a greenhouse at ~22 °C for 2 months before application.

Greenhouse conditions and pot experiment setting

The experiment was carried out under greenhouse condition at temperature of 22 °C, relative humidity (RH) of ~70% and light regime of ~150 micromole /m^2 /S PAR (photosynthetically active radiation). Milled residues and pre-decomposed manure were uniformly mixed with soil samples at 10 g kg $^{-1}$ dry soil. The mixed samples were added into pots of 5 L size (20 cm length and 15 cm diameter) were pre decomposed for one month at soil moisture level of. Soil moisture was set at the pF3.5 to simulate the dry season effect of crop residues mineralization which is typical for the study area (Abera et al., 2012b). The pots were watered to the desired optimum soil moisture level (pF2.5) before planting maize. The chemical fertilizers, Yaramila (YM), Urea + DAP (UrDp) were applied at the rate of 300, 200 + 100 kg ha^{-1}, respectively, after raising the soil moisture content to pF2.5. Overall, a factorial combination of nine fertilizer sources and three harvesting times were arranged in completely randomized design (CRD) in three replications. Gibe 2 maize variety was planted in pots as a test crop in this study. Accordingly, initially three maize seeds were planted per pot and later two seeds were thinned after fully emerged. The amount of water lost was compensated for by measuring soil moisture using time domain reflectrometry (TDR) probe.

Allometric parameters such as plant height (PH, cm), leaf number (LN), leaf length (LL, cm), maize shoot dry weight (SDW) and root dry weight (RDW) below and above biomass production (g/plant) at 30, 60 and 90 days of sampling were assessed. At every sampling period, the three top leaf length were measured, while shoot and root biomass were destructively sampled at 30, 60 and 90 days for dry weight determination. Root biomass was immediately sampled after shoot biomass harvest. The soil adhering to roots was manually cleaned and then further washed under running water (on mesh sieve). The root and shoot biomass were separately collected, air dried and then oven dried at 72 $^{\circ}$C for 48 h, before determining dry weight (Abera et al., 2012b).

Analyses of soil and plant samples

The nutrient contents of soil, residues, and manure were analysed prior organic materials amendment in triplicates. Likewise, the concentration of plant nutrients in maize shoot biomass was determined at the end of the experiment. Total P was determined by Vanadomolybdophosphoric acid method (VM method), while total C was determined based on loss on ignition (LOI) method. Total N was determined by Kjeldahl method, whereas K by ash extract-flame photometer. Boron was determined by ash extract–Azomethine-H (Colorimetric) method. The elements: Ca, Mg, Mn, Fe, Cu, Zn and Ni were determined by ash extract–flame atomic absorption. Sulfur, S was determined by aqua regia digest–turbidimetric method.

Assessment methods of mineral fertilizer values

The relative growth rate of shoot/root was estimated in relation to maximum growth rate obtained by applying compounded chemical fertilizer YM as follows:

$$\text{Relative shoot/root growth rate} = \frac{\text{Shoot/root dry weight at t2- Shoot/root dry weight at t1}}{\text{Sampling days t2- sampling days t1}}$$

Nutrient ratios (NRs) of N, P and K were determined across sampling periods as follows:

NRs = N/P, N/K, P/K.

The ratios of nutrients were calculated on weight base, for example g N in dry shoot was divided by g P in dry shoot of maize plant.

Amount of nutrients recovery (NRy) as affected by application of chemical and organic fertilizers relative to the nutrient omitted (NoM) were estimated.

$$\text{NRy} = \frac{\text{Nutrients recovered from treated pots - Nutrients recovered from NoM pots}}{\text{Amount of nutrinets applied through fertilizers}}$$

Mineral fertilizer equivalency (MFE) was calculated as follows.

$$\text{MFE} = \frac{\text{Amount of nutrients recovered from organic materials}}{\text{Amount of nutrients recovered from UrDp}} \times 100$$

Statistical data analyses

The data were subjected to analyses of variance using general linear model (GLM) of MINITAB soft ware packages. The mean value differences were separated by least significant difference and declared at 5% level of significance.

RESULTS

Organic materials

Organic materials were variable in N, P and K contents. For example, manure contains 1.53, 0.49 and 2.23% of N, P and K, while soybean residue contains 1.32, 0.37 and 2.78% of N, P and K, respectively (Table 1). Chick pea residue contained remarkably high amount of iron (233 mg kg^{-1}); but low in N (0.58%) and P (0.09%) and high C: N (90). Similarly, maize residue was also low in N (0.5%) and high C: N (110) (Table 1).

Effect of fertilizer sources on maize allometry

Fertilizer sources significantly ($p<0.05$) influenced maize

maize growth performance indicators such as plant height (PH), leaf number (LN) and leaf length (LL) across sampling periods (Data not shown). The highest PH was displayed in soils supplied with inorganic fertilizers, YM and UrDp than organic fertilizers. Application of YM increased PH by 60, 67 and 98%, in 30, 60 and 90 sampling days, respectively, as compared to that of nutrient omitted (NoM) pots. Likewise, YM increased LL by 87, 79, and 60%, in 30, 60 and 90 days of sampling, respectively. The amendment of FYM, SB and CP resulted in significantly higher PH and LL relative to other organic residues (Data not shown). On the other hand, the application of CHP and M residues reduced maize allometric parameters as compared to NoM pots across sampling periods.

Shoot and root dry biomass production of maize were significantly affected by fertilizer sources across sampling periods (Figure 1). The results revealed that fertilizer supply modulated shoot and root dry biomass production by affecting allometric parameters. Accordingly, the effect of inorganic fertilizer application was superior to organic materials. The application of YM also increased shoot and root dry biomass by 60% and 85%, respectively, as compared to NoM. In the same way, UrDp application increased shoot and root dry biomass production by 76% and 87% as compared to NoM. Except for SB, other organic materials amendment resulted in lower shoot and root dry biomass production than that of NoM. The shoot and root dry biomass production in increasing order were recorded M<CHP< HB<CP<FYM<SB.

Effect of fertilizer sources on shoot and root growth rates

Fertilizer sources significantly ($p<0.05$) affected relative growth rates of shoot and root (Figure 2). The high, medium and low dry shoot and root growth rate were attained with inorganic fertilizers (UrDp and YM), SB and FM, and crop residues (M, CHP, and HB) application. For instance, UrDp application increased shoot growth rate by 200 and 222% at 60 and 90 days of sampling, respectively, as compared to that of NoM. The shoot to root ratio slightly increased as N supply increased by inorganic fertilizer application. As a result, the high shoot to root ratios was exhibited in the order of YM>UrDp > SB, whilst the low shoot to root ratios were noted in the order of C > FYM > CP > HB > M > CHP during 30 days. Similar trends were exhibited during 60 and 90 days (Data not shown).

Nutrient uptake and recovery

Nitrogen, P and K uptake and recovery were significantly ($p<0.05$) affected by types of fertilizer sources during each sampling day (Figures 3 and 4). During the first 30 days of sampling all organic materials resulted in slightly lower N uptake than the control soil. Nitrogen uptake showed increasing trends with all chemical and organic fertilizer sources over the sampling periods (Figure 3). For example, N uptake was increased by 846, 1214 and 2567% with the application of UrDP, YM and FYM, respectively, during 90 of sampling.

N and P recovery showed slightly increasing trends from organic (SB, CP and FM) and chemical (UrDp and YM) fertilizer sources across sampling period. Some organic residues displayed negative N recovery during 60 and 90 days of sampling, while FYM has shown positive N recovery at 60 days of sampling and afterwards that implied gradual net N mineralization over time. The application of chemical fertilizers, UrDp and YM, resulted in significantly higher N and P nutrients recovery, while FYM exhibited the highest P recovery (Figures 3 and 4).

Mineral fertilizer equivalency of organic materials

Mineral fertilizer equivalency (MFE) of organic materials was calculated as compared to YM. MFE of organic materials ranged from -160% with CHP to 63% with FYM based on N recovery, from -186 % with CHP to 1222% with FYM based on P recovery and from -201% with CHP to 3% with SB based on K recovery (Table 2). MFE value of organic materials appeared mostly negative as their nutrient uptake was very low as compared to the non-fertilized (control) pots, thereby limited maize growth and dry biomass production, possible due to the slow rate of residue decomposition. This revealed low MFV of crop residues over short term. On the other hand, fertilizer value of chemical fertilizers (UrDp and YM) was found to be superior to organic residues in increasing nutrient uptake, maize growth and dry biomass production.

Effect of fertilizer sources on nutrient ratios

The N:P ratio ranged from 1.9 - 4.6, 2.7 - 8.8 and 4.6 - 28.4 at 30, 60 and 90 days of samplings, respectively. The remarkably higher N:P ratio (28.4) was observed with the application of CHP. Likewise, N: K ratio ranged from 0.2 - 0.4, 0.2 - 0.7 and 0.3 -1.1 at 30, 60 and 90 days of samplings, respectively. The K:P ratio also ranged from 5.5 - 13.9, 7.0 - 16.9 and 4.5 - 17.3 at 30, 60 and 90 days of samplings, respectively. The nutrient ratios at 90 days of samp-

Figure 1. Effect of fertilizer sources on shoot and root dry weight (g $plant^{-1}$). SB = Soybean; CP = Cow pea; HB = Haricot bean; CHP = Chick pea; M = Maize; FYM = Farmyard manure; YM = Yaramila and C = Control. Different letters among columns within the sampling date are significantly different at (P<0.x). The data in column are mean values of three replications.

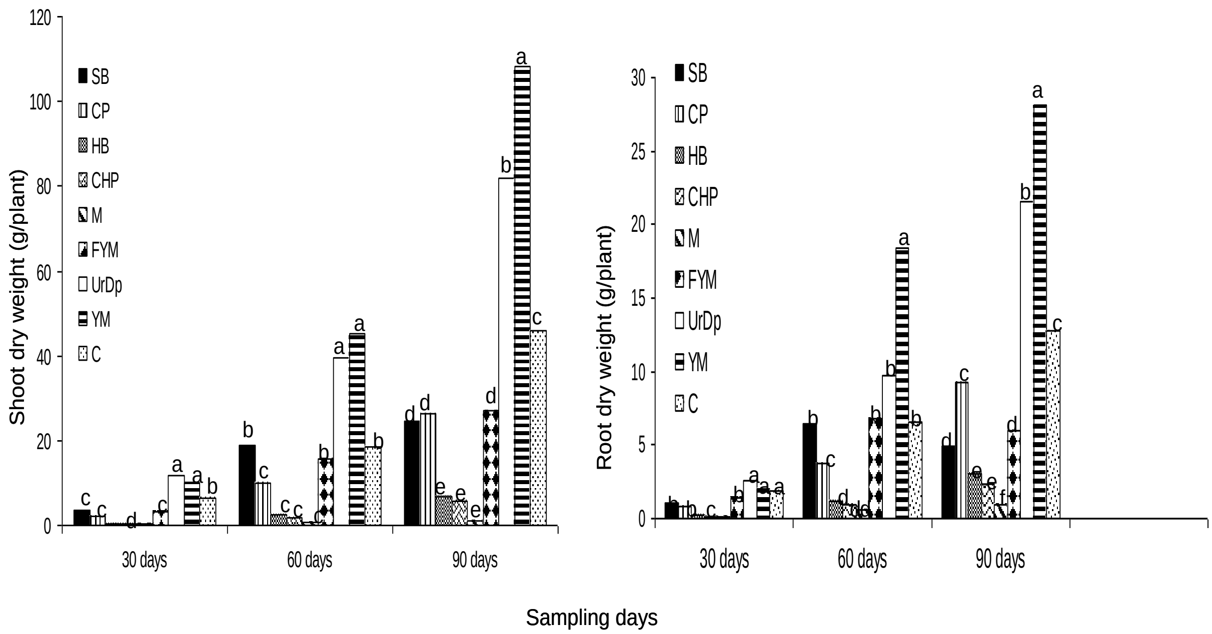
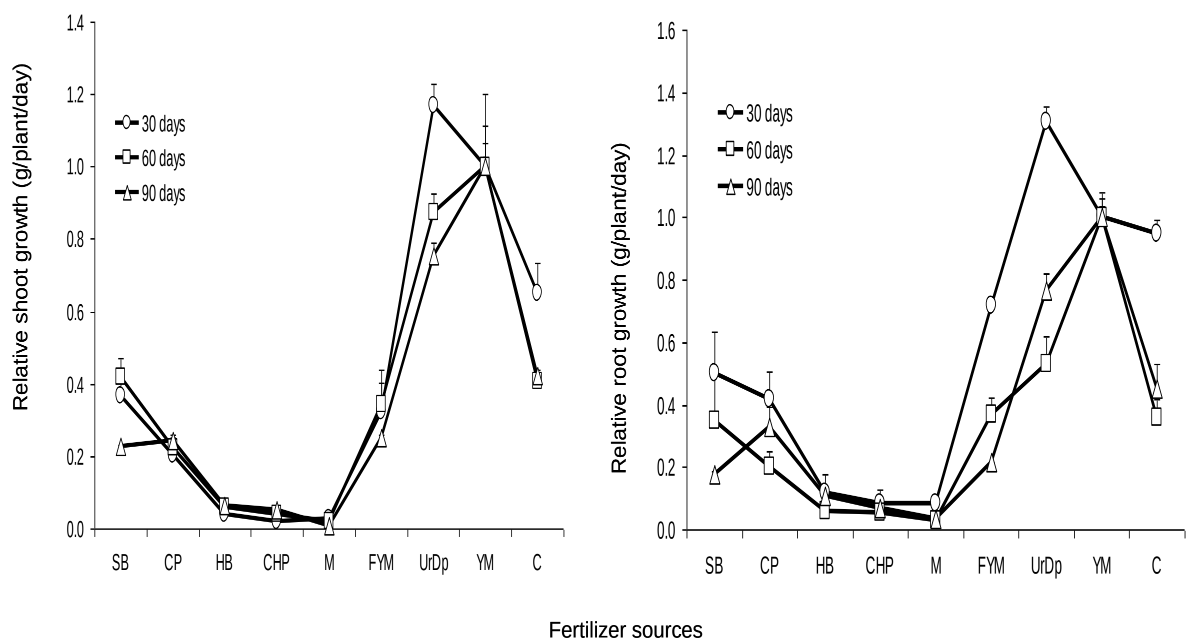


Figure 2. Dry shoot and root growth rates (g $plant^{-1}$ day^{-1}) as affected by fertilizer sources. SB = Soybean; CP = Cow pea; HB = Haricot bean; CHP = Chick pea; M = Maize; FYM = Farmyard manure; YM = Yaramila and C = Control.



ling were greater than that of 30 and 60 days of samplings. Fertilizers sources affected the nutrient ratios; 90 days of sampling except for high N: P with CP and CHP (Table 3). This suggest that nutrient ratio is a poor tool to detect the nutrient limitation / or poor to assess the nutrient release ability of different fertilizer sources.

DISCUSSION

Effect of fertilizer sources on allometric parameters

Comparative investigation of the effect of chemical and organic fertilizer sources showed that organic materials (crop residues and manure) significantly ($p<0.05$) reduced maize plant height (PH), leaf length (LL), relative shoot and root growth rate (g plant^{-1}day^{-1}), dry shoot and root biomass, and nutrient uptake (NU), nutrient recovery (NRy) and MFE as compared to both chemical fertilizers and nutrient omitted (non-amended) soils. This indicates that the application of organic materials led to more nutrient deficiency of maize, perhaps through transient microbial immobilization of nutrients from soils (Tables 2, 3 and 4). Plants are regarded as nutrient-deficient or nutrient-limited if their production (relative growth rate (RGR); and annual herbage production increment; grain yield, etc) is lower by a certain percentage (e.g. 10% or 20% than the maximum reachable at high nutrient supply (Fohse et al., 1988). In the present study, the reduction in growth and dry biomass production of maize was more than 50% with the application of organic materials (Figures 1 and 2). This could be attributed to the coincidence of microbial immobilization of nutrients with crop growth or due to very slow or insufficient nutrient release for the crop (*A*bera et al., 2012b). This implied that soil microorganisms out competed plants for available soil nutrients particularly for N. Because soil microorganisms colonize and utilize organic residues for energy and cell building as the C: N ratios of all the materials expect farmyard manure were above the threshold level (C:N > 20) for N mineralization (Sun et al., 2014). On the other hand, soil microbial N immobilization may play an important role in regulating the soil N retention capacity and prevent nitrogen loss through leaching in the form of NO_3^- (Bengtson & Bengtsson, 2005).

Despite the fact that the organic materials left pre decomposed for one month before application to soils, their nutrient contribution tends to be very small, depicted with the poor maize agronomic performance during the first 30 days of sampling. The performance of maize was also not apparently improved during the next 60 and 90 days of sampling period that could be attributed to their poor quality, low N and high C: N ratio (Table 1). Indeed, considerable differences were observed among the organic materials nutrient release in synchrony with plant growth requirement, as depicted by significantly varied maize allometric parameters. In general, organic resources set in the order of FYM > SB > CP > HB> CHP > M in benefiting maize growth and production as fertilizers sources. Interestingly, FM and SB amendment resulted in relatively better maize allometric parameters, reflecting that they are better quality litter (higher in N concentration and low in C: N ratio) than others organic materials.

The chemical fertilizer, YM resulted in higher PH, LN and LL, faster rates of shoot and root growth, and very stout and green maize production, followed by UrDp. This could be attributed to the fact that YM is a compound fertilizer that provides diverse essential nutrients such as N (23%), P_2O5 (10%), K_2O (5%), S (3%) and MgO (2%), and Zn (0.3%). In general chemical fertilizers, YM and UrDP significantly enhanced shoot and root growth rates across sampling periods as compared to organic fertilizers. This implied that the chemical fertilizers rapidly released nutrients for immediate uptake and efficient utilization. This proves the vital importance of the synchronization of nutrient release with crop growth requirement. Interestingly, shoot to root ratio was relatively low with certain organic fertilizers, while chemical fertilizers slightly improved shoot to root ratios. This perhaps related to the limited nutrient availability from poor quality residues that limit photosynthesis and biomass production. Evidence of more biomass allocation to roots was reported in response to deficiency of N and P, but the effect of N is usually stronger (Andrews et al., 1999; De Groot et al., 2003).

Nutrient uptake and recovery

As N is the main nutrient that limits crop production, and organic materials are major source of it, this report focuses mainly with N uptake and recovery. Fertilizer sources evidently affected maize shoot nutrient uptake (N, P and K). Higher nutrient uptake of maize biomass was observed with the application of chemical fertilizers (Figures 3 and 4). The application of chemical fertilizers, YM and UrDp, not only improved the uptake of N and P, but also enhanced the uptake of K across sampling periods (Data not shown), confirming the long established fact that the application of N and P fertilizers may improve the uptake of K from inherent soil, as long as sufficient soil K level exist. During the first 30 days, all organic materials displayed negative nutrient recovery plausibly indicating net N immobilization, while some organic residues displayed negative N recovery even during 60 and 90 days of sampling. In contrast, FYM showed positive N recovery at 60 days and afterwards. The most likely explanation is that perhaps it undergone gradual net N mineralization. This is in conformity with previous study that has shown similar negative nutrient recovery of maize, when poor quality residues (HB and M) were applied and positive N recovery when high quality residue was applied. Thus, attributed to net N immobilization during the early phase of plant residues decomposition that in turn limits plant growth hence their ability to extract other nutrients from the soil (Abera et al., 2012b).

Figure 3. Estimated nitrogen uptake and recovery (g plant^{-1}) as affected by chemical and organic fertilizers sources across sampling days. SB = Soybean; CP = Cow pea; HB = Haricot bean; CHP = Chick pea; M = Maize; FYM = Farmyard manure; YM = Yaramila and C = Control. The data in column are mean values of three replications. Mean separation among fertilizer sources in a column were based on each sampling days.

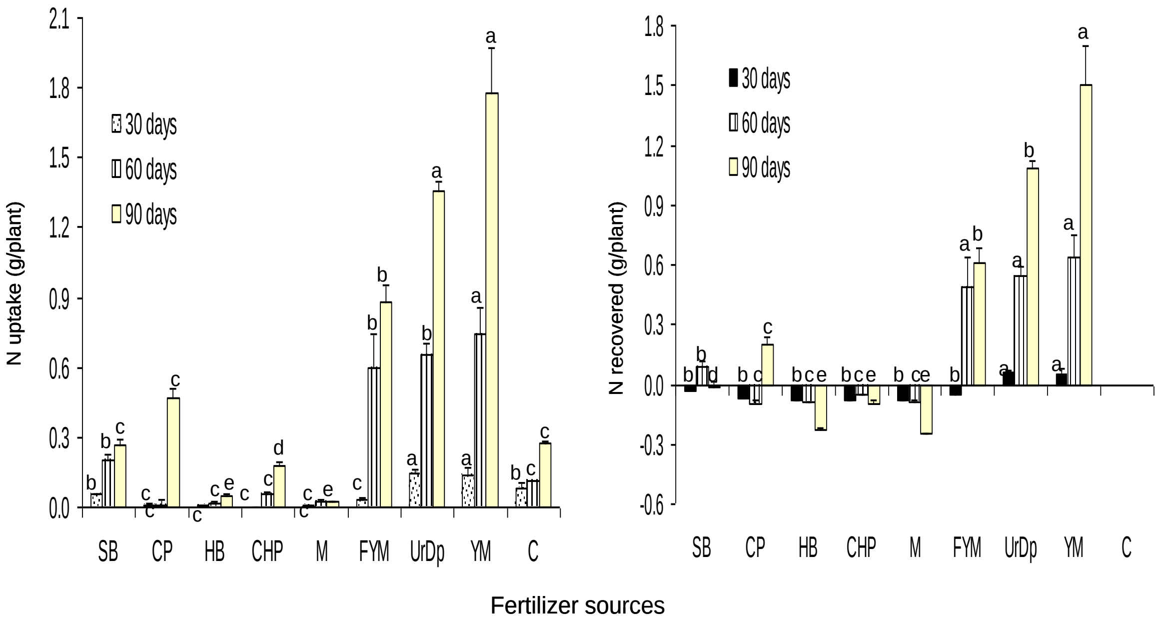
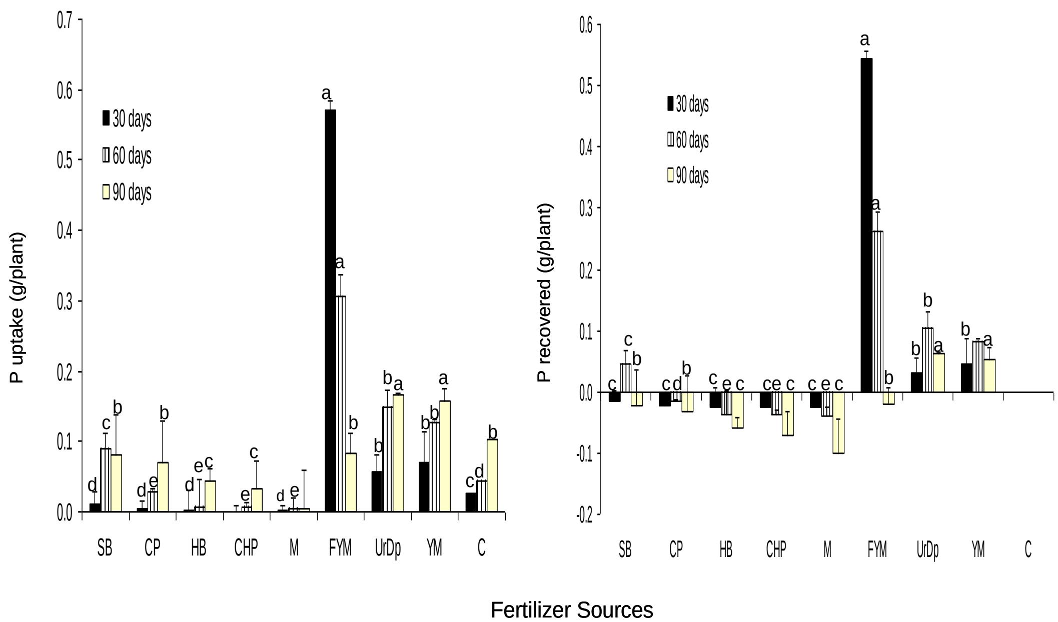


Figure 4. Estimated P uptake and recovery (g plant^{-1}) as affected by chemical and organic fertilizers sources across sampling days. The data in column are mean values of three replications. Mean separation among fertilizer sources in a column were based on each sampling days.



sources was substantially increased over the sampling periods; from 0.05 g plant^{-1} at 30 days to 0.27 g plant^{-1} (440%) at 60 days and then to 0.59 g plant^{-1} (1080%) at 90 days, while average P uptake over sampling periods

Table 1. Biochemical characteristics of organic residues.

Organic residues	Total element (%)						Mineral (mg kg^{-1})						C/N	Ash%
	TC	TN	P	K	Mg	S	Mn	Fe	Cu	Zn	B	Ni		
SB	49.9A	1.32B	0.37B	2.78C	0.67A	0.91A	94.3B	71.2C	8.2A	39.3B	45.4A	Trace	38B	14.0A
CP	52.3A	1.28BC	0.20D	3.71A	0.30B	0.54AB	73.3B	2.6D	4.3B	21.1C	24.7B	Trace	41B	9.8C
HB	53.1A	1.08C	0.13E	2.90C	0.20BC	0.35AB	47.0C	14.5D	5.1B	15.6C	20.7B	Trace	49B	8.5C
CHP	51.1A	0.58D	0.09F	3.32B	0.43B	0.28AB	43.6C	232.5A	8.1A	11.3C	23.0B	Trace	90A	11.9B
M	53.3A	0.50D	0.33C	2.92C	0.10C	0.17B	18.9D	15.8D	4.0B	17.1C	4.2C	Trace	110A	8.2C
FYM	39.0B	1.53A	0.49A	2.23D	0.40B	0.48AB	176.0A	113.9B	4.7B	61.0A	20.3B	50±1	25C	ND

SB = Soybean; CP = Cow pea; HB = Haricot bean; CHP = Chick pea; M = Maize; FYM = Farmyard manure.

Table 2. Estimated mineral fertilizer equivalency (%) of organic fertilizers and UrDp as compared to YM based on nutrient recovery of maize shoot biomass at different sampling periods.

Source of fertilizer	N			P			K		
	30	60	90	30	60	90	30	60	90
SB	-58	15	-0.7	-32	57	-42	-53	3.0	-22
CP	-140	11	13	-49	-19	-63	-161	-1	-27
HB	-150	-14	-15	-54	-44	-111	-189	-27	-45
CHP	-160	-9	-7	-57	-45	-134	-201	-27	-47
M	-154	-14	-17	-56	-47	-186	-195	-31	-55
FYM	-99	63	41	1222	318	-38	-115	19	-17
UrDp	115	86	72	70	127	118	1884	44	90
YM	100	100	100	100	100	100	100	100	100
Lsd (5%)	25	40	25	23	43	75	23	49	70

SB = Soybean; CP = Cow pea; HB = Haricot bean; CHP = Chick pea; M = Maize; FYM = Farmyard manure; YM = Yaramila and C = Control.

On average, N uptake of maize shoots from all fertilizer was slightly constant from 0.083 g plant^{-1} to 0.085 g plant^{-1}. Average K uptake was also significantly increased from 0.146 g plant^{-1} during 30 days to 0.616 g plant^{-1} (323%) at 60 days and then to 0.926 g plant^{-1} (534%) during 90 days. Uptake of N and K was closely related with biomass yield (shoot +root), while P uptake was not. Similar result was reported in maize grain nutrient uptake. Nitrogen recovery from both organic fertilizer (SB, CP and FM) and chemical fertilizer sources (UrDp and YM) showed slightly increasing trends from the first sampling date (30 day) to the last sampling date (90 day), This perhaps attributed to increase in root length and diameter that improve the ability of plants to absorb nutrients and water.

Effect of fertilizer sources on nutrient ratios

The nutrient concentrations and ratios (N:P, N:K and P:K) can be proximal evidence whether the applied organic materials are sufficient fertilizer sources or not for crop production. This is because of the fact that nutrients released during decomposition is expected to be taken up by the growing plant. However, there are controversial reports regarding the use of nutrient ratios as an index of nutrient supply of soils or organic fertilizers, since there are variation of nutrient ratios among species of plants, within species, growth stage of crops, types of plant parts and plasticity of species (Güswell, 2004). For example, earlier studies suggested that N:P < 10 indicates N limitation, while N:P > 20 indicates P limitation and accordingly the N:P ratio between 10 and 20 suggested to indicate sufficiency of both N and P or they co-limit (Gong et al., 2011). However, the N:P ratios of the present study of maize shoot biomass was similar with both chemical fertilizers and organic materials application. The nutrient ratios showed low N status in plant tissue, despite the fact that sufficient chemical fertilizers were applied via YM and UrDp. On the other hand, nutrient ratios of N:K and K:P indicated that P and K concentrations in maize plant tissues exist in optimum status (Table 3). Thus, the biomass nutrient ratios may not be always be good indicator of relative availability of nutrients that could be attributed to variations in edaphic and climatic factors in addition to plant species. For example, although biomass N: P ratios reflect the relative availability of N and P, the correspondence is not exact because of

Table 3. Estimated maize shoot biomass nutrient ratios as affected by application of chemical and organic fertilizer sources at different growth stages.

	N:P			N:K			K:P		
	30	60	90	30	60	90	30	60	90
SB	4.6±0.4	3.3±2.9	4.6±4.4	0.3±0.0	0.4±0.2	0.5±0.1	13.9±0.6	7.0±2.9	7.4±1.4
CP	2.7±0.3	6.5±0.1	17.2±2.5	0.2±0.0	0.4±0.0	0.9±0.1	10.9±0.5	16.9±0.5	7.6±2.6
HB	3.1±0.3	2.7±0.4	7.0±1.0	0.4±0.0	0.2±0.0	0.3±0.0	7.6±0.4	11.1±1.7	4.5±0.2
CHP	2.1±0.5	8.8±0.4	28.4±6.7	0.4±0.1	0.6±0.0	1.1±0.1	5.7±0.5	13.9±0.4	5.0±0.7
M	3.7±0.2	5.4±2.2	6.1±3.3	0.4±0.0	0.7±0.1	0.9±0.1	8.9±0.3	8.4±3.8	6.0±0.6
FYM	1.9±0.2	7.2±3.5	11.9±3.2	0.3±0.0	0.7±0.1	1.3±0.1	5.5±0.0	10.8±5.4	8.2±1.7
UrDp	2.5±0.5	5.7±2.8	12.0±6.2	0.3±0.0	0.6±0.0	0.5±0.0	7.5±1.2	9.8±4.7	15.1±1.2
YM	1.9±0.1	5.9±0.4	14.1±1.8	0.4±0.0	0.4±0.0	0.7±0.0	4.7±0.1	15.6±0.1	17.3±1.6
C	3.2±0.4	2.5±0.2	6.3±0.4	0.4±0.0	0.2±0.0	0.3±0.0	8.5±0.1	11.2±1.0	9.5±0.9

SB = Soybean; CP = Cow pea; HB = Haricot bean; CHP = Chick pea; M = Maize; FYM = Farmyard manure; YM = Yaramila and C = Control.

homeostatic regulation of plants: 10-fold variation in N:P supply ratios cause only two-to- three-fold variation in biomass N:P ratios (Güswell & Koerselman, 2002). Another explanation is that plastic responses of plants to N and P cause up to 50- fold variation in N: P ratios, associated with differences in root allocation, uptake, biomass turnover and reproductive output (Güswell, 2004). Moreover, nutrient ratios depend not only on the availability of nutrients for uptake and utilization, rather on the growth stages as plant tissue sampling was performed over 90 days. The nutrient ratios increased as plant growth stage increased from seedling to tasseleing stage. This suggests that nutrient ratio may be not dependable to be used as a tool to assess soil nutrient limitation. For example, in the present study application of sufficient chemical fertilizers showed non-sufficiency level in terms of nutrient ratio depicting that nutrient ratio provide false indication of nutrient limitation for plant growth.

Mineral fertilizer equivalency (MFE) of organic materials

The MFE of organic materials ranged from -201% with CHP to 63% with FYM, indicating that the fertilizer value of organic materials vary depending on its quality and ability of nutrient release on a short term basis. This implies that FYM could provide 63% of the mineral value of YM over the sampling periods, while CHP resulted in soil nutrient deficit by about 200% over the sampling period. This resulted in limited maize growth, dry biomass production and substantial maize nutrient stress, possibly due to ephemeral immobilization of nutrients by microorganism during decomposition. The negative MFE value with organic materials amendment implies slow nutrient release and low maize nutrient uptake as compared to the non-fertilized (control) soils. Fertilizer value of chemical fertilizers (UrDp and YM) was found to be superior in higher nutrient uptake and better maize dry biomass production to organic materials and control soils. Nevertheless application of YM was significantly higher in MFE values of N, P and K than that of UrDp because of YM is a compound of multi elements. The MFE of FYM appeared to be better than most organic residues indicating that FYM (C: N= 25) might be a better quality organic material for crop production in low input framing systems of southern Ethiopia. Mineral fertilizer equivalency of FYM in terms of P supply was found to be superior to both YM and UrDp during 30 and 60 days of samplings, and decreased at 90 90 days of sampling implying that its P release had depleted over time.

In nutshell, the best tools for assessing the mineral fertilizer value of organic materials are identified. These are relative growth rates, nutrient uptake, nutrient recovery (NRy) and mineral fertilizer equivalency (MFE) which are fundamental to revitalize their benefit with regards to assessment of the mineral fertilizer value of organic materials for the benefit of smallholder farmers.

CONCLUSION

Simple and cost effective methods of assessing the mineral fertilizer value of organic materials were identified. The results showed that organic materials addition further aggravated the soil nutrient stress, while the inorganic fertilizers amendment ameliorated the nutrient deficiency and thereby improved maize allometric parameters. The former can be attributed to the transient net microbial immobilization of nutrients (N and P) at the early phase of residue decomposition. Of the organic materials amended to soils, FYM displayed better MFE in relative to the compound inorganic fertilizer, YM. The superiority of YM in influencing maize allometric parameters, nutrient uptake and recovery suggested that the study soil has limitation in terms of nutrient balance. Therefore, the importance of balanced fertilizer supply is highly evident in maintaining soil fertility for sustainable crop production. Of the tools tested N: P ratio was similar for both inorganic and organic fertilizers supply, implying that it is less reliability to be used as an evaluation tool.

The present findings demonstrate that application of organic materials with high C: N ratio exacerbate the nutrient stress under low input cropping systems. This calls for innovative integration of organic and chemical fertilizers to complement the drawbacks of each fertilizer source enforcing our earlier achievements.

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