Agroforest Syst
DOI 10.1007/s10457-016-0035-8

Improving maize production through nitrogen supply from ten rarely-used organic resources in Ghana

Samuel T. Partey · Naresh V. Thevathasan · Robert B. Zougmoré · Richard F. Preziosi

Received: 14 July 2015 / Accepted: 14 October 2016

Abstract Where there is limited availability of conventional fertilizers, the use of organic materials is considered a viable alternative to increase the productive capacity of soils. Many potential plant residues remain underutilized due to limited research on their use as a nutrient source. In this study, the nitrogen supplying capabilities of ten rarely-used leaf biomass sources (*Acacia auriculiformis, Baphia nitida, Albizia zygia, Azadirachta indica, Senna siamea, Senna spectabilis, Tithonia diversifolia, Gliricidia sepium, Leucaena leucocephala* and *Zea mays*) were tested based on their nutrient content, N mineralization patterns and effect on maize yield (in comparison with inorganic fertilizer). N mineralization was studied in the laboratory using an incubation experiment. Field trials were also established using a randomized complete block design. Plant residues were applied at 5 t dry matter ha^{-1} a week before planting maize while fertilizer was split-applied at 90 kg N ha^{-1} on designated plots. From the results on plant residue chemistry, most of the plant residues recorded relatively high N concentration ($\geq$24.9 g kg^{-1}) and low C/N ratio ($\leq$20.1) although neither N content nor C/N ratio significantly ($p > 0.05$) affected their N mineralization patterns. Leaf biomass application of *B. nitida*, *A. auriculiformis*, *A. zygia* and maize stover resulted in an initial net N immobilization that lasted for 14 days. Application of all plant materials significantly increased the biological yield and N uptake of maize with *G. sepium* and *T. diversifolia* producing the greatest impact especially in the major rainy season. Relative to the control, total grain yield after four cropping seasons was comparable between inorganic fertilizer (9.2 t ha^{-1}), *G. sepium* (8.8 t ha^{-1}) and *T. diversifolia* (9.4 t ha^{-1}) treatments. The results on maize biological yield were significantly correlated with the effects of the treatments on N uptake. The findings suggest that in locations where inorganic fertilizers are limited, leaf biomass from *G. sepium* and *T. diversifolia* could offer the most suitable option in comparison with the other species used in this study.

Keywords Organic agriculture · Soil fertility · Maize production · Underutilized species

S. T. Partey (✉)
Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
e-mail: stpartey@gmail.com;
S.Partey@cgiar.org

N. V. Thevathasan
School of Environmental Sciences, University of Guelph, Guelph, ON N1G 2W1, Canada

S. T. Partey · R. B. Zougmoré
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Bamako, Mali

R. F. Preziosi
Faculty of Life Sciences, The University of Manchester, Manchester, UK

Published online: 20 October 2016

Introduction

Maize (*Zea mays* L.) is an important staple crop in most of Africa and accounts for more than 50 percent of total cereal production in the region. Ragasa et al. (2013) reports that the bulk of maize produced goes into food consumption in sub-Saharan Africa (SSA) making it an important crop for food security. The development and productivity of the livestock and poultry sectors also depend on the maize value chain since maize is a major component of poultry and livestock feed (Ragasa 2014). Despite the availability of improved germplasm, average maize yield in SSA remains one of the lowest (1.6 t ha^{-1}) in the world (FAOSTAT 2010). In most parts of SSA, soil fertility decline is a major reason for the low yields of major food crops including maize. Unsustainable farming activities have severely depleted soil nutrients throughout much of the farming regions. Although fertilizer consumption increased steadily in recent times in SSA (Sommer et al. 2013), average fertilizer use rates are still considered too low and ineffective for sustaining crop production and maintaining soil fertility (Gruhn et al. 2000; Ragasa et al. 2013). A recent survey identified factors including high costs of fertilizers due to removal of subsidies, lack of access to fertilizers and inefficient marketing systems as the major constraints to the sub-optimal application of fertilizers (Chapoto and Ragasa 2013; FAO 2012).

With the limited availability of conventional fertilizers, the use of organic materials is considered a viable alternative to increase the productive capacity of soils. In SSA, the use of organic resources is identified as a mainstream opportunity for agricultural development in the region due to their relative availability (Partey and Thevathasan 2013). The most common organic resources employed in soil fertility programs in SSA include plant residues, green manure sources of leguminous crops, animal manure, mulches and tree/shrub prunings from agroforestry practices (Partey et al. 2011). Animal manures are bulky, have unpleasant scent and have high potential for harbouring pathogens (Bernal et al. 2009; Crutzen et al. 2008) making the use of plant residue sources the preferable option. Recent research of high quality plant residues (with relatively high N concentration and low C/N ratio) applied to agricultural fields indicated tremendous yield increase for major food crops in SSA (Beedy et al. 2010). The addition of such organic resources to the soil reportedly improves soil temperature, enhances soil structure, maintains high soil nutrient status and improves soil moisture retention (Chivenge et al. 2011; Makumba et al. 2006).

In Ghana, the use of organic resources is included in soil management practices but many potential plant residues remain underutilized due to limited research and knowledge transfer (Partey et al. 2011; Partey and Thevathasan 2013). Their utilization could complement and contribute to solving nutrient deficiencies due to limited application of inorganic fertilizers. Some of these organic resources are the leaf biomasses of *Acacia auriculiformis, Baphia nitida, Albizia zygia, Azadirachta indica, Senna siamea, Senna spectabilis, Tithonia diversifolia, Gliricidia sepium and Leucaena leucocephala.* Despite having limited use in Ghanaian cropping systems, studies in Kenya, Nigeria, Uganda and other parts of SSA have shown that leaf biomass application increase crop yields even on depleted soils (Beedy et al. 2010; Ikerra et al. 2007; Mucheru-Muna et al. 2014; Nziguheba et al. 2000). Biomass transfers from these species could therefore contribute to the development of sustainable soil improvement practices that improve and sustain crop production for smallholder farmers in Ghana. However, the development and adoption of such soil fertility improvement practices will be influenced by research results that reveal the viability of organic sources for improving soil fertility (particularly N availability) and crop yields. It was therefore the objective of this study to determine the N supplying capabilities of rarely-used plant residues for maize production in Ghana. The selection of the plant materials were based on their relative abundance at the study location, experimental evidence of their use as organic fertilizers in SSA (Gachengo et al. 1999; Jama et al. 2000; Partey et al. 2011), their residue N concentrations and underutilized status for soil management at the study location (Partey and Thevathasan 2013). The research was based on the hypothesis that with increased net N mineralization from the leaf biomass of the tested species, the biological yield of maize will increase because of a resultant increase in N availability and uptake.

Materials and methods

Study site

The study was conducted at the agroforestry demonstration field of the Faculty of Renewable Natural

Resources (FRNR), Kwame Nkrumah University of Science and Technology, Kumasi (KNUST), Ghana, located at Lat 01 43°N and Long 01 36°W. The research area had been fallowed for five years prior to the execution of this study. The area falls within the moist semi-deciduous forest zone of Ghana and is characterized by a bimodal rainfall pattern, with the major wet season between May and July. This area also experiences a short dry season in August and a long one between December and March. The annual rainfall of the area ranges between 1250 and 1500 mm. The area is characterized by a mean annual temperature of 26.6 °C. Precipitation data recorded during the research period is shown in Fig. 1. Soil type at study site is a ferric acrisol.

Initial soil characterization

Prior to establishing the field experiment, soil samples were randomly collected from the surface 20 cm from 16 locations at the site for characterization using a stainless steel soil auger (25 inch. in diameter). The samples were composited and homogenized into one sample. They were then air-dried and sieved to 2-mm before being sub-divided into four sub-samples for analysis. Soil pH was measured with a glass electrode (1: 1 H_2O), particle size was determined using the hydrometer method, total N was determined by dry combustion using a LECO TruSpec^{TM} CN autoanalyzer (LECO Corporation), organic carbon was determined by the dichromate oxidation method (Motsara and Roy 2008), cation exchange capacity was measured using flame photometry of ammonium acetate extracts, available P by the ammonium phosphomolybdate method and available K by flame photometry (Toth and Prince 1949). The initial physicochemical properties of the soil at the study location were: pH (4.6), total N (0.42 g kg^{-1}), available P (2.1 mg kg^{-1}), available K (224.0 mg kg^{-1}), organic C (13.8 g kg^{-1}), CEC (5.8 cmol kg^{-1}), sand (67.6 %), silt (28.4 %) and clay (4.0 %).

Plant residue quality and N mineralization study

Plant residue characterization

Organic resources used in the experiment were the leaf biomass of *A. auriculiformis, B. nitida, A. zygia, A. indica, S. siamea, S. spectabilis, T. diversifolia, G. sepium, Z. mays* and *L. leucocephala*. Table 1 presents a summary of the botany, growth habits and general uses of the species used in the experiment. In order to characterize the plant residues for quality parameters, portions of their leaf biomass including soft stems

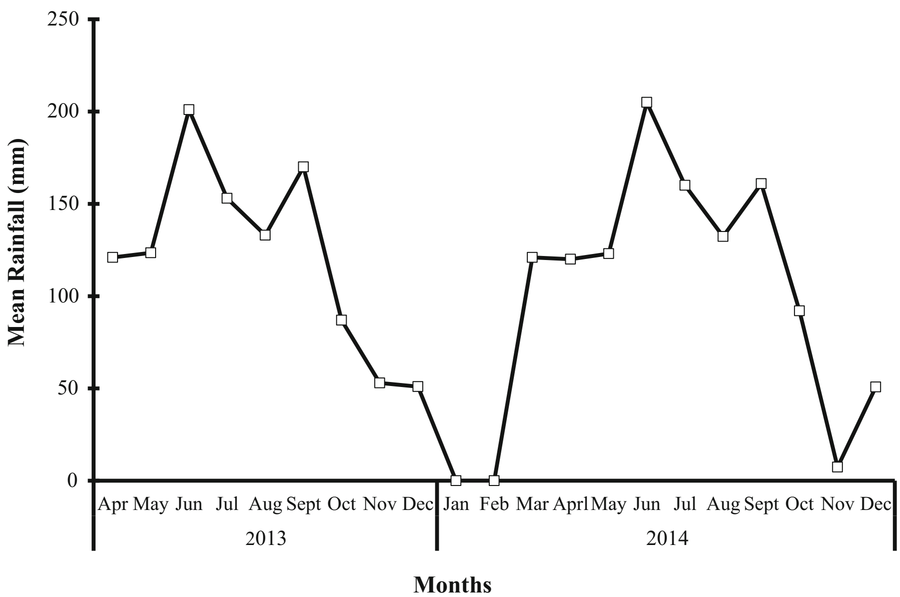

Fig. 1 Monthly rainfall distribution recorded during the experimental periods in 2013 and 2014. Data points are the means of three replicates

were oven dried at 65 °C for 72 h, ground with a grinder and sieved to 0.5 mm. The sieved plant materials were analyzed for total N, P, K, Ca, Mg and C in four replicates. For all analyses, total N and C were determined simultaneously by dry combustion using a LECO TruSpec™ CN autoanalyzer (LECO Corporation) while total K, Ca, and Mg were determined by the dry ashing and atomic absorption spectrophotometry as described by Eneji et al. (2005). Phosphorus was also determined in an ash solution by the ammonium phosphomolybdate method (Motsara and Roy 2008). The general chemical characteristics of all plant materials used are reported in Table 2.

Quantification of N mineralization with plant residue application

An incubation experiment was performed under laboratory-controlled conditions to determine N mineralization from the selected plant residues. Briefly, 125 mg (equivalent to 5 t ha^{-1}) of 0.5 mm sieved dried and ground leaf biomass of each plant were mixed with 50 g of 2 mm sieved sandy-loam soil in 250 ml beakers and incubated in the dark at 28 °C for 84 days. Unamended soil was used as a control. There were 24 beakers for every treatment. Prior to amending the soil, the soil was preconditioned by moistening to 50 % water holding capacity for 5 days. This was done to stabilize microbial activities (Xiang et al. 2008). The beakers were covered with aluminium foil to prevent rapid loss of water due to evaporation. Soil moisture content was checked by weighing every other day and the weight loss was replaced by addition of distilled water. The moisture content was kept constant at 50 % water holding capacity of the soil throughout the experiment. Nitrogen mineralization was determined by measuring the production of mineral N ($NH_4^+ + NO_3^-$) at 3, 7, 14, 28, 56, and 84 days of incubation. Ammonium and nitrate were determined by extracting 25 g of moist soil with 2 M KCl at a 1: 4 soil and extractant ratio. Ammonium and nitrate in the KCl extract were determined by the indophenol blue and phenoldisulphonic acid methods respectively (Motsara and Roy 2008). All measurements were done by sampling four beakers per treatment on every sampling period. Analysis was done separately for each soil sample in a beaker. Net cumulative N mineralized from the different treatments was calculated by subtracting the inorganic N of the unamended control from amended soils at each sampling time (Abbasi and Khizar 2012; Sistani et al. 2008).

Field experiment

The field experiment was conducted in four continuous planting seasons: major rainy season of 2013, minor rainy season of 2013, major rainy season of 2014 and minor rainy season of 2014. For both years, major rainy season experiments were conducted between June and August while minor rainy season experiments were conducted between September and November. The experiment was first set up during the major rainy season of 2013 using a randomized complete block design with four replicates. The treatments included a control; leaf biomass sources of each plant (all applied at 5 t dry matter ha^{-1}); and mineral fertilizer applied at a recommended rate of 90 kg N ha^{-1} (Partey et al. 2014a). Fresh leaf biomasses of the species (including soft stems) were harvested from nearby fields at the study location for the planting seasons in which leaf biomass treatments were imposed. Each treatment was allocated to a plot size of 3.2 m × 3.2 m. There were 44 plots in all. The tree leaf biomass was generally applied in whole with random cuts into smaller pieces where necessary. The biomass was surface applied on designated plots by hand and incorporated by hoeing a week before planting. The 90 kg N ha^{-1} inorganic fertilizer treatment (in the form of urea) was split applied on the designated plots at 7 days after planting (DAP) and 30 DAP using 40 and 60 % of the total fertilizer respectively. To reduce the effects of P deficiency, all 44 plots received one time basal P application (in the form of triple superphosphate) at a rate of 60 kg ha^{-1} 7 DAP. The experimental treatments were applied in only the first three seasons: major rainy season of 2013, minor rainy season of 2013; and major rainy season of 2014. In the fourth cropping season (minor rainy season of 2014), the residual effects of the treatments were evaluated (no plant residue treatments or fertilizer applied). During planting, four maize seeds (of a local variety named 'obatampa') were sown per hill at 0.4 × 0.8 m spacing and thinned to two plants per hill within 2 weeks. Thinning was done to ensure that plants left in the field had uniform growth. As much as possible, confounding effects of

Table 1 Botanical information and general uses of the species used in the experiment

Scientific name	Common name (s)	Family	Description	Climate range	Uses	References
Baphia nitida	Camwood/African sandalwood	Fabaceae	Shrub; grows to about 10 m in the forest	Tropical	Source of dye, fodder, soil improvement, ornamental and medicinal	Chong et al. (2009)
Albizia zygia	Igbo (nyie avu); Swahili (nongo); Yoruba (ayin rela)	Fabaceae	A deciduous tree; grows to about 30 m	Tropical	Fodder, timber, source of tannins, soil improvement, erosion control, fuelwood	Orwa et al. (2009)
Tithonia diversifolia	Mexican sunflower, tree marigold, Mexican tournesol, Nitobe chrysanthemum	Asteraceae	Fast growing shrub; grows to about 3 m tall.	Tropical	Fodder, green manure for soil improvement, live fence, ornamental	ICRAF (1997)
Senna spectabilis	Calceolaria shower, pisabed, cassia, yellow shower	Fabaceae	Shrub and medium-sized tree; grows to about 15 m tall	Tropical and tolerant of cool conditions	Apiculture, fodder, fuelwood, soil improvement, ornamental	Orwa et al. (2009)
Gliricidia sepium	Gliricidia, tree of iron, St. Vincent plum, Mexican lilac, mother of cocoa, quick stick, Nicaraguan cacao shade	Fabaceae	Shrub; grows to a height of 2–15 m	Tropical	Apiculture, fodder, fuelwood, soil improvement,	Orwa et al. (2009)
Leucaena leucocephala	Leucaena, Jumpy-bean, wild tamarind, lead tree, white popinac, white leadtree, horse tamarind	Fabaceae	Shrub and medium-sized tree; grows to about 15 m tall	Tropical	Apiculture, fodder, source of gum or resin; fuelwood, soil improvement	Orwa et al. (2009)
Acacia auriculiformis	Earpod wattle, Papuan wattle, auri, earleaf acacia, northern black wattle, Darwin black wattle	Fabaceae	An evergreen tree; grows to about 15 m tall	Mostly tropical but also found in some temperate ecologies as an introduced ornamental	Street landscaping, soil improvement, fuelwood and charcoal production	Starr et al. (2003)
Senna siamea	Kassod tree, yellow cassia, cassia, Thailand shower, thai copper pod, iron wood, Siamese senna, Bombay blackwood, black-wood cassia	Fabaceae	A medium-size, evergreen tree growing up to 18 m tall	Lowland tropics with a monsoon climate	Source of tannin, fuelwood, fodder, food, soil improvement, ornamental	Orwa et al. (2009)
Azadirachta indica	Neem	Meliaceae	Small to medium-sized tree, usually evergreen, grows up to 15 (30 max.) m tall	Lowland tropics	Source of tannin and lipids, fuelwood, fodder, food, soil improvement, medicinal	Orwa et al. (2009)

Table 2 Chemical characteristics of plant materials used in the experiment

Plant materials	N ($g\ kg^{-1}$)	P	K	Ca	Mg	C	C/N
A. auriculiformis	20.5 ± 1.2	1.4 ± 0.1	19.0 ± 1.3	14.6 ± 1.2	3.3 ± 0.1	453.2 ± 3.7	22.1 ± 0.1
A. indica	21.2 ± 1.3	1.1 ± 0.0	13.3 ± 1.1	18.2 ± 1.4	4.7 ± 0.2	490.0 ± 4.3	23.1 ± 1.3
A. zygia	24.3 ± 2.0	2.2 ± 0.1	21.0 ± 2.1	15.4 ± 1.1	2.7 ± 0.1	479.0 ± 4.1	19.7 ± 1.2
B. nitida	39.2 ± 1.8	2.2 ± 0.1	23.0 ± 2.3	14.1 ± 1.4	2.3 ± 0.2	475.0 ± 5.0	12.1 ± 0.8
G. sepium	27.7 ± 1.1	2.9 ± 0.2	18.0 ± 1.5	7.9 ± 1.2	6.6 ± 0.2	455.3 ± 2.1	16.4 ± 1.2
L. leucocephala	24.6 ± 1.4	1.9 ± 0.1	19.0 ± 1.3	12.7 ± 1.1	6.3 ± 0.1	460.2 ± 2.3	18.7 ± 1.1
Maize stover	12.2 ± 1.3	1.2 ± 0.1	20.6 ± 1.7	4.2 ± 0.2	2.9 ± 0.1	420.0 ± 3.1	34.4 ± 1.1
S. siamea	18.2 ± 1.1	2.1 ± 0.1	21.0 ± 1.6	5.8 ± 0.1	3.3 ± 0.0	460.1 ± 2.6	25.3 ± 0.9
S. spectabilis	28.9 ± 1.6	2.5 ± 0.1	23.0 ± 1.4	6.4 ± 0.1	5.3 ± 0.1	451.2 ± 1.3	15.6 ± 1.0
T. diversifolia	32.6 ± 1.7	4.1 ± 0.2	41.0 ± 2.4	13.5 ± 1.3	9.1 ± 0.3	450.2 ± 1.2	13.8 ± 0.6

Values are the means of four replicates ± standard error

crop residues were controlled by removing all maize biomass after every trial including the roots.

Determination of maize productivity and nutrient uptake

At physiological maturity, all maize plants within 4-m^2 were sampled. To determine stover yield, the plants were uprooted from the soil after watering the surface soil. Uprooting plants was necessary to minimize confounding effects of crop residues. The above-ground residues were separated from the roots and oven dried in the laboratory at 65 °C for 72 h. To determine nutrient uptake, samples of the oven-dried above-ground residue were ground to pass through a 0.5-mm sieve and analysed for N concentration. Nitrogen was determined using LECO TruSpec™ CN autoanalyzer (LECO Corporation). Nitrogen uptake was determined by multiplying the dry-matter yields by the N nutrient concentration of the above-ground biomass. Grain yield was determined by collecting cobs into perforated harvesting bags and sun drying over two weeks until the grain reached 12.5 % moisture content (the acceptable moisture content in most African markets) (Kurwakumire et al. 2014).

Statistical analysis

Data on maize agronomic performance, nutrient uptake, and N mineralization were analysed using the analysis of variance (ANOVA) test. Repeated measures analysis was used to determine seasonal effects and the effect of season and treatment interaction on maize biological yield. Where test results were significant, the least significant difference method was used for mean comparison at a 5 % probability level. Correlation and regression analyses were used to establish significant relationships among measured parameters. All statistical analyses were conducted with Genstat 12 software (VSN International).

Results

Plant residue quality and N mineralization patterns

The C and nutrient content of the ten plant materials used in the study are reported in Table 2. Nitrogen ranged from 12.2 $g\ kg^{-1}$ in maize stover to 39.2 $g\ kg^{-1}$ in the leaf biomass of *B. nitida*. The C/N ratio also ranged from 12.1 in *B. nitida* to 34.4 in maize stover. Among the plant materials, leaf biomass of *T. diversifolia* recorded the greatest level of P and K. Calcium concentration was lowest in maize stover while Mg content was significantly ($p \leq 0.05$) higher in *T. diversifolia*.

Figure 2 shows the N mineralization patterns of the plant materials used in the experiment. Immobilization occurred in soil amended with leave from *A. auriculiformis*, *A. zygia*, *B. nitida*, maize stover and *S.*

siamea during the first 13 days of the incubation. Nitrogen immobilization also occurred in *A. indica* for 3 days. The highest levels of net N mineralization were observed for soil amended with *T. diversifolia*, *G. sepium*, *L. leucocephala* and *S. spectabilis*. Cumulative net N mineralization was significantly higher with *T. diversifolia* (93.5 mg N kg^{-1}) at the end of the incubation period (84 days). The net N mineralization rate in *T. diversifolia* was approximately 1.1 mg N kg^{-1} day^{-1}. Cumulative net N mineralization was comparable between *G. sepium* and *L. leucocephala* and lowest for *A. auriculiformis*, *A. zygia*, *B. nitida*, maize stover and *S. siamea.* A correlation and regression analysis indicated that cumulative net N mineralization of the plant materials were not significantly related to their initial N concentrations ($r^2 = 0.14$, $p = 0.28$) or C/N ratios ($r^2 = 0.26$, $p = 0.14$).

Effects of treatments on N uptake and biological yield of maize

Table 3 shows the nitrogen uptake of maize as influenced by the treatments. In general, the application of plant residues increased N uptake on all amended plots. However, among treatments, N uptake was significantly ($p < 0.001$) higher on plots that received either inorganic fertilizer or *T. diversifolia* leaf biomass application. With respect to the biological yield of maize, repeated measures analysis showed significant ($P < 0.001$) seasonal effects and interaction with treatments (Table 4). Both grain and stover yields of maize where greater during the major rainy season trials. During the major rainy season of 2013, grain yield ranged from 1.0 to 3.1 t ha^{-1}. Among treatments, grain yield was significantly higher on plots that received inorganic fertilizer or *T. diversifolia* leaf biomass (Table 5). Relative to the control, grain yield in the major season of 2013 was about 300 % greater with the application of either inorganic fertilizer or *T. diversifolia* leaf biomass. Comparable results were also obtained during the 2013 major season for *A. auriculiformis*, *A. zygia*, *B. nitida*, maize stover, and *S. siamea*. The effect of *G. sepium* leaf biomass aplication was comparable to that of *S. spectabilis*, *A. indica* and *L. leucocephala*. In the minor season of 2013, grain yield ranged from 0.8 t ha^{-1} for the control to 2.2 t ha^{-1} with the application of *T. diversifolia* leaf biomass. Statistically, the greatest effects were obtained from plots that received inorganic fertilizer, *G. sepium* or *T. diversifolia* treatments. The effects of *A. auriculiformis*, *A. zygia*, *B. nitida*, maize stover, and *S. siamea* were comparable and intermediate. Maize grain yield was also significantly ($p < 0.001$) higher with inorganic fertilizer, *G. sepium* and *T. diversifolia* treatments during

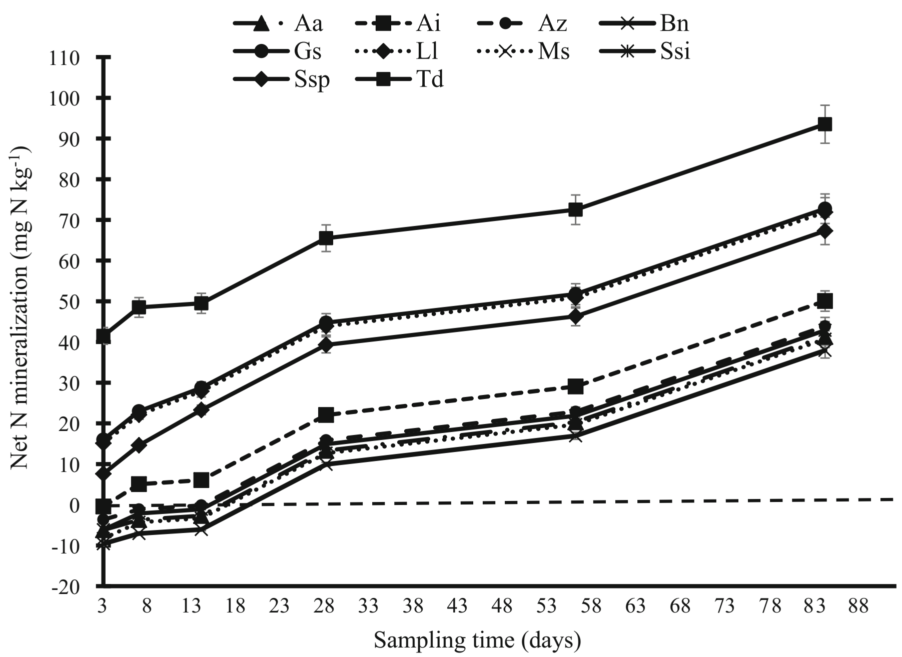

Fig. 2 Cumulative net N mineralization of ten plant materials over 84 days of incubation under laboratory controlled conditions. Data points are the means of four replicates. *Error bars* are standard error of means. *Aa Acacia auriculiformis*, *Az Albizia zygia*, *Ai Azadirachta indica*, *Bn Baphia nitida*, *GS Gliricidia sepium*, *Ll Leucaena leucocephala*, *Ms* maize stover, *Ssi Senna siamea*, *Ssp Senna spectabilis*, *Td Tithonia diversifolia*

Table 3 Nitrogen uptake (kg ha^{-1}) of maize as affected by inorganic fertilizer and plant residue treatments

Treatments	N uptake
A. auriculiformis	40.3 ± 2.7
A. indica	47.4 ± 1.7
A. zygia	36.8 ± 2.0
B. nitida	36.9 ± 1.2
Control	15.6 ± 1.0
Fertilizer	60.4 ± 3.4
G. sepium	55.0 ± 2.5
L. leucocephala	50.6 ± 4.6
Maize stover	33.5 ± 1.7
S. siamea	39.1 ± 3.4
S. spectabilis	51.9 ± 1.5
T. diversifolia	61.7 ± 3.1
LSD	5.40
P value	0.001

Values are the means of four replicates ± standard error

LSD least significant difference

Table 4 Repeated measures analysis for the effect of treatment and time on maize grain and stover yields

Variable	Source of variation	df	MS	P value
Grain yield	Treatment	11	2.19	<0.001
	Time	3	7.34	<0.001
	Treatment × time	33	0.27	<0.001
Stover yield	Treatment	11	9.95	<0.001
	Time	3	8.12	<0.001
	Treatment × time	33	0.85	<0.001

df degrees of freedom; *MS* mean sum of squares

the major rainy season trial of 2014. On average, maize grain yield was about twice that of the control when maize received either inorganic fertilizer, *G. sepium* or *T. diversifolia* leaf biomass. During the minor rainy season of 2014, the residual effects of *T. diversifolia* and inorganic fertilizer (although significantly higher than the control) were comparatively lower than was observed in previous trials. Generally, there were comparable results among treatments between growing seasons. Total cumulative grain yield obtained from the four experimental trials showed *T. diversifolia*, *G. sepium* and inorganic fertilizer recorded the highest grain yield of maize (Table 5). Among the cropping seasons, trials in the major rainy seasons of 2013 and 2014 recorded the highest mean grain yield (approximately 2.2 t ha^{-1}).

Similar to the results on grain yield, the application of treatments increased maize stover yield in all four crop growing seasons (Table 6). Maize stover yield was significantly ($p < 0.001$) higher on plots that received inorganic fertilizer or *T. diversifolia* treatments. In 2014, maize stover yield ranged from 3.1 to 6.1 t ha^{-1} in the major rainy season and 2.1 to 4.7 t ha^{-1} in the minor rainy season. Similar to the results in 2013, *G. sepium, T. diversifolia* and inorganic fertilizer recorded the highest effects in the 2014 major season trial. The residual effects were generally comparable among treatments. At the end of the four experimental trials, total stover yield ranged from 10.1 t ha^{-1} for the control to 22.0 t ha^{-1} for *T. diversifolia*.

Discussion

Considering that crop production is a soil-based industry, agricultural technologies that improve soil fertility in agroecosystems have major implications for reducing hunger by enhancing crop yields. The use of organic amendments is strongly recommended for the highly weathered tropical soils of SSA that are normally low in organic matter (Vanhie et al. 2015). In this study, the nitrogen supplying capabilities of ten rarely-used plant residues were tested on maize production in comparison with inorganic fertilizer. The N supplying capabilities of the species were determined based on their residue chemistry (N content and C/N ratio); N mineralization and effect on maize performance. The use of substrate N concentration and C/N ratio as indices for determining the decomposability and N mineralization of plant residues in agroforestry systems is well documented (e.g. Constantinides and Fownes 1994; Kumar and Goh 1999; Partey et al. 2014b; Gentile et al. 2008). According to Troeh and Thompson (2005), the break-even point for decomposing and increased net N mineralization of organic materials within a few weeks is a C: N ratio of about 32: 1. Whilst this assertion was consistent with the pattern of N mineralization recorded for *T. diversifolia*, *G. sepium*, *L. leucocephala* and *S. spectabilis* (Fig. 2), it contradicted that of *B. nitida*, *A. zygia*, and *A. indica* which

Table 5 Grain yield (t ha^{-1}) of maize as affected by inorganic fertilizer and plant residue treatments during the minor and major rainy seasons of 2013 and 2014

Treatments	2013		2014		Total grain yield
	Major rainy season[a]	Minor rainy season[b]	Major rainy season[a]	Minor rainy season[b]	
A. auriculiformis	2.0 ± 0.1	1.5 ± 0.2	2.1 ± 0.1	1.6 ± 0.2	7.4 ± 0.5
A. indica	2.5 ± 0.2	1.6 ± 0.1	2.4 ± 0.1	1.7 ± 0.2	8.3 ± 0.3
A. zygia	1.9 ± 0.2	1.3 ± 0.2	1.8 ± 0.2	1.7 ± 0.2	6.7 ± 0.6
B. nitida	1.9 ± 0.1	1.3 ± 0.1	1.9 ± 0.2	1.6 ± 0.2	6.8 ± 0.4
Control	1.0 ± 0.1	0.8 ± 0.1	1.4 ± 0.1	0.9 ± 0.1	4.1 ± 0.2
Fertilizer	3.0 ± 0.2	2.1 ± 0.3	2.8 ± 0.1	1.3 ± 0.1	9.2 ± 0.4
G. sepium	2.7 ± 0.2	2.0 ± 0.3	2.6 ± 0.2	1.5 ± 0.4	8.8 ± 0.4
L. leucocephala	2.5 ± 0.1	1.8 ± 0.3	2.5 ± 0.2	1.5 ± 0.2	8.3 ± 0.6
Maize stover	1.8 ± 0.1	1.2 ± 0.1	1.8 ± 0.1	1.6 ± 0.2	6.4 ± 0.3
S. siamea	1.9 ± 0.1	1.6 ± 0.2	2.1 ± 0.1	1.6 ± 0.2	7.2 ± 0.6
S. spectabilis	2.6 ± 0.2	1.8 ± 0.2	2.5 ± 0.1	1.5 ± 0.1	8.4 ± 0.3
T. diversifolia	3.1 ± 0.2	2.2 ± 0.3	2.8 ± 0.1	1.4 ± 0.1	9.4 ± 0.5
LSD	0.27	0.36	0.26	0.26	0.68
P value	<0.001	<0.001	<0.001	<0.001	<0.001

Values are the means of four replicates ± standard error

LSD least significant difference

[a] Growing season was between June and August

[b] Growing season was between September and November

had C/N ratios narrower than the critical maximum of 32: 1. However, the results are consistent with previous studies that demonstrated that the C/N ratio of plant residues may not be a reliable indicator of organic matter decomposition and N mineralization in both temperate and tropical regions (Ostrowska and Porebska 2015; Palm and Sanchez 1990; Partey et al. 2012). While these contrasting results do not undermine the applicability of substrate initial N concentrations and C/N ratio as plant litter quality indicators, they imply the necessity for prudent decision making in selecting plant residues for soil fertility improvement based on multiple plant and soil factors. It is therefore reasonable to assume that unlike the initial N concentrations of the plant residues and their C/N ratios, their decomposition and N mineralization may be related to: (1) different decomposer communities that may have developed on the plant residues based on their intrinsic qualities (Cobo et al. 2002); (2) other plant quality variables such as lignin, polyphenol, hemicellulose concentrations and their ratios with N; (3) C/N ratio of soil; as well as (4) the water retention capacity of plant residues which although unassessed in this study have been shown to influence plant residue decomposition and N mineralization (Palm et al. 2001; Iqbal et al. 2013; Makkonen et al. 2013). Based on the results on N mineralization, leaf biomass application of *T. diversifolia*, *G. sepium*, *L. leucocephala* and *S. spectabilis* are expected to improve soil N availability and subsequent uptake by crops for increased biological yield. The accelerated mineralization of N in *T. diversifolia* and *G. sepium* biomass may limit their use for long term sustenance of soil fertility and soil organic matter. Farmers may have to apply these materials every cropping season which may have significant economic implications.

The differential effects of the plant residues on the biological yield of maize reflected their differences in quality and N supplying capabilities. Apart from nutrient supply, plant residue quality has implications for other soil properties such as soil moisture, pH and cation exchange capacity which are intrinsically linked to soil organic matter content and quality (Bhupinderpal-Singh and Rengel 2007). The overall

Table 6 Maize stover yield (t dry matter ha^{-1}) as affected by inorganic fertilizer and plant residue treatments during the minor and major rainy seasons of 2013 and 2014

Treatments	2013		2014		Total stover yield
	Major rainy season[a]	Minor rainy season[b]	Major rainy season[a]	Minor rainy season[b]	
A. auriculiformis	4.5 ± 0.1	4.0 ± 0.2	4.7 ± 0.1	4.7 ± 0.3	17.8 ± 0.5
A. indica	5.4 ± 0.1	4.3 ± 0.2	5.3 ± 0.2	4.1 ± 0.2	19.0 ± 0.6
A. zygia	4.5 ± 0.1	4.0 ± 0.2	4.3 ± 0.1	4.7 ± 0.2	17.2 ± 0.3
B. nitida	4.4 ± 0.1	3.8 ± 0.1	4.4 ± 0.1	4.6 ± 0.3	17.1 ± 0.4
Control	2.6 ± 0.1	2.3 ± 0.1	3.1 ± 0.1	2.1 ± 0.0	10.1 ± 0.3
Fertilizer	6.3 ± 0.1	5.1 ± 0.1	6.1 ± 0.2	4.0 ± 0.2	21.5 ± 0.4
G. sepium	5.8 ± 0.1	4.8 ± 0.1	5.8 ± 0.2	4.3 ± 0.2	20.7 ± 0.3
L. leucocephala	5.3 ± 0.2	4.5 ± 0.3	5.7 ± 0.4	4.5 ± 0.3	19.9 ± 1.1
Maize stover	4.0 ± 0.1	3.7 ± 0.1	4.1 ± 0.1	4.7 ± 0.2	16.5 ± 0.4
S. siamea	4.3 ± 0.1	4.0 ± 0.2	4.5 ± 0.2	4.7 ± 0.2	17.4 ± 0.5
S. spectabilis	5.6 ± 0.1	4.6 ± 0.1	5.6 ± 0.1	4.3 ± 0.1	20.1 ± 0.2
T. diversifolia	6.2 ± 0.1	5.3 ± 0.1	6.0 ± 0.1	4.5 ± 0.1	22.0 ± 0.3
LSD	0.34	0.41	0.44	0.62	1.29
P value	<0.001	<0.001	<0.001	<0.001	0.001

Values are the means of four replicates ± standard error

LSD least significant difference

[a] Growing season was between June and August

[b] Growing season was between September and November

effects of the treatments on maize may therefore be a combination of factors beyond just N supply (which was the emphasis of this study). Generally, the results showed increased biomass yield, grain yield and N uptake of maize in all treatments compared with the control. However, the greatest effects occurred on plots that received either *G. sepium* or *T. diversifolia* treatments especially during the major rainy season; possibly because of increased water availability. These observations are consistent with the results of previous studies (Gachengo et al. 1999; Nziguheba et al. 2000; Partey and Thevathasan 2013). In Western Kenya, field trials conducted by Nziguheba et al. (2000) showed that the addition of *T. diversifolia* green manure tripled total maize yields after six seasons compared to the control and inorganic fertilizer treatments. Experimental trials under similar tropical conditions in Malawi, Brazil and other parts of SSA reported multiple increments in maize grain yield with the application of *G. sepium* prunings (Barreto et al. 2012; Beedy et al. 2010; Makumba et al. 2006). Further, the results on maize yield showed the nitrogen supplying capabilities of the plant residues may be more closely correlated with their N mineralization patterns than their N composition. It was evident that even with the application of 196 kg N ha^{-1} from *B. nitida* leaf biomass (Fig. 3), plots amended with *B. nitida* leaf biomass produced some of the smallest effects on maize grain and stover yield. Considering the significantly low net N mineralization of soil amended with *B. nitida* leaf biomass, the release of N may not have synchronized with crop N demand. According to Salas et al. (2003), organic resources contain significant concentrations of organic nutrients that undergo biological decomposition and mineralization processes to become available for crop use. It is therefore reasonable to assume that with high N mineralization, high N uptake could be expected, which may consequently result in high crop yield. This assertion would explain why the plant materials with high cumulative net N mineralization such as *G. sepium* and *T. diversifolia* recorded the greatest impact on the biological yield of maize. The argument is further supported by the significant ($p < 0.001$)

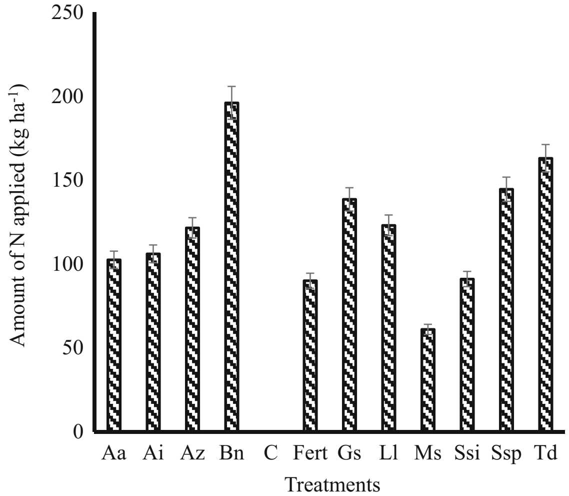

Fig. 3 Amount of N applied from inorganic fertilizer and plant residues used in the experiment. Data points are the means of four replicates. *Error bars* are standard error of means. *Aa Acacia auriculiformis*, *Az Albizia zygia*, *Ai Azadirachta indica*, *Bn Baphia nitida*, *C* control, *Fert* inorganic fertilizer, *GS Gliricidia sepium*, *Ll Leucaena leucocephala*, *Ms* maize stover, *Ssi Senna siamea*, *Ssp Senna spectabilis*, *Td Tithonia diversifolia*. All plant materials were applied at 5 t dry matter ha^{-1}, inorganic fertilizer was applied at 90 kg N ha^{-1}

positive correlation obtained between the amount of N mineralized and the biological yield and N uptake of maize (Table 7). However, the collection of large amounts of biomass and the resultant labour demands may limit large-scale adoption of *T. diversifolia* and *G. sepium* biomass for maize production. In addition, it is evident (Tables 5, 6) that, compared with the species with least N mineralization rates, *T. diversifolia* and *G. sepium* may have low residual impacts due to accelerated decomposition and N release. This may necessitate regular application of their biomass during crop growing seasons which may pose greater financial burden on resource-poor farmers; especially where labour requirements may be high for biomass collection.

Conclusions

From the results on plant residue quality, most of the plant residues recorded relatively high N concentration and low C/N ratio although these properties were not always significantly related to their N mineralization patterns. Application of *B. nitida*, *A. auriculiformis, A. zygia* leaf biomass and maize stover resulted in an initial net N immobilization that lasted for 14 days. On the effect of the treatments on maize, the results confirmed that all the treatments could increase maize yield in the study area. However, the effect will be greater with either inorganic fertilizer, *G. sepium* or *T. diversifolia* leaf biomass application. Relative to the control, total grain yield after four cropping seasons was found to be comparable between inorganic fertilizer (9.2 t ha^{-1}), *G. sepium* (8.8 t ha^{-1}) and *T. diversifolia* (9.4 t ha^{-1}) treatments. The results showed that differential effects of the species on maize biological yield were attributed to their differences in N mineralization. It was evident that with high N mineralization, high N uptake could be expected, which may consequently result in high crop yield. We therefore suggests that in places where inorganic fertilizers are limited, leaf biomass from *G. sepium* and *T. diversifolia* could offer the most suitable option in comparison with the other species

Table 7 Pearson correlation coefficients for the relationship between N uptake, N mineralization and the total biological yield of maize

	Total grain	Total stover	N added	Cumulative net N mineralized	N uptake
Total grain	1				
Total stover	0.98^{***}	1			
N added	0.37^{ns}	0.42^{ns}	1		
Cumulative net N mineralized	0.91^{***}	0.97^{***}	0.38^{ns}	1	
N uptake	0.99^{***}	0.99^{***}	0.42^{ns}	0.96^{***}	1

N = 44

ns not significant at $p \leq 0.05$

*** significant at $p \leq 0.001$

used in this study. This notwithstanding, labour requirements and cost implications for harvesting leaf biomass should be considered in adopting this practice.

Acknowledgments This research was supported by the International Foundation for Science, Stockholm, Sweden, through a grant to Samuel Partey as part of efforts to promote the use of less utilized leguminous species in developing countries. The authors are grateful to the logistical support of the CGIAR Research Program on Climate Change Agriculture and Food Security (CCAFS). We also appreciate the contributions of the two anonymous reviewers and the Associate Editor who took time to read every sentence and made corrections where applicable.

References

Abbasi MK, Khizar A (2012) Microbial biomass carbon and nitrogen transformations in a loam soil amended with organic–inorganic N sources and their effect on growth and N-uptake in maize. Ecol Eng 39:123–132

Barreto AC, Chaer GM, Fernandes MF (2012) Hedgerow pruning frequency effects on soil quality and maize productivity in alley cropping with *Gliricidia sepium* in Northeastern Brazil. Soil Till Res 120:112–120

Beedy TL, Snapp SS, Akinnifesi FK, Sileshi GW (2010) Impact of *Gliricidia sepium* intercropping on soil organic matter fractions in a maize-based cropping system. Agric Ecosyst Environ 38:139–146

Bernal MP, Alburquerque JA, Moral R (2009) Composting of animal manures and chemical criteria for compost maturity assessment. A review. Bioresour Technol 100:5444–5453

Bhupinderpal-Singh, Rengel Z (2007) The role of crop residues in improving soil fertility. In: Marschner P, Rengel Z (eds) Nutrient cycling in terrestrial ecosystems, Soil Biology, vol 10. Springer, Berlin, pp 183–214

Chapoto A, Ragasa C (2013) Moving in the right direction? Maize productivity and fertilizer use and use intensity in Ghana. IFPRI, Washington, DC **(Discussion Paper 01314)**

Chivenge P, Vanlauwe B, Gentile R, Six J (2011) Organic resource quality influences short-term aggregate dynamics soil organic carbon and nitrogen accumulation. Soil Biol Biochem 43:657–666

Chong KY, Tan HTW, Corlett RT (2009) A checklist of the total vascular plant flora of singapore: native, naturalised and cultivated species. Raffles Museum of Biodiversity Research, National University of Singapore, Singapore, p 273

Cobo JG, Barrios E, Kass DCL, Thomas RJ (2002) Decomposition and nutrient release by green manures in a tropical hillside agroecosystem. Plant Soil 240:331–342

Constantinides M, Fownes JH (1994) Nitrogen mineralization from leaves and litter of tropical plants: relationship to nitrogen, lignin and soluble polyphenol concentrations. Soil Biol Biochem 26:49–55

Crutzen PJ, Mosier AR, Smith KA, Winiwarter W (2008) N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmos Chem Phys 8:389–395

Eneji AE, Yamamoto S, Wen G, Inanaga S, Honna T (2005) A comparative evaluation of wet digestion and dry ashing methods for the determination of some major and minor nutrients in composted manure. Toxicol Environ Chem 87:147–158

FAO (2012) Analysis of incentives and disincentives for maize in Ghana. FAO, Rome

FAOSTAT (2010) Food and Agricultural Organization of the United Nations (FAO), FAO statistical database. http://www.faostat.fao.org. Accessed 28 May 2015

Gachengo CN, Palm CA, Jama B, Othieno C (1999) Tithonia and Senna green manures and inorganic fertilizers as phosphorus sources for maize in western Kenya. Agrofor Syst 44:21–36

Gentile R, Vanlauwe B, Chivenge P, Six J (2008) Interactive effects from combining fertilizer and organic residue inputs on nitrogen transformations. Soil Biol Biochem 40:2375–2384

Gruhn P, Goletti F, Yudelman M (2000) Integrated nutrient management, soil fertility, and sustainable agriculture: current issues and future challenges. International Food Policy Research Institute, Washington, DC, p 31

ICRAF (1997) Using the wild sunflower, *T. diversifolia*, in Kenya. International Centre for Research in Agroforestry, Nairobi, p 5

Ikerra ST, Semu E, Mrema JP (2007) Combining *Tithonia diversifolia* and *Minjingu* phosphate rock for improvement of P availability and maize grain yields on a chromic acrisol in Morogoro, Tanzania. In: Bation A, Waswa B, Kihara J, Kimetu J (eds) Advances in integrated soil fertility management in sub-Saharan Africa: challenges and opportunities. Springer, Dordrecht, pp 333–344

Iqbal A, Beaugrand J, Garnier P, Recous S (2013) Tissue density determines the water storage characteristics of crop residues. Plant Soil 367:285–299

Jama B, Palm CA, Buresh RJ, Niang AI, Gachengo C, Nziguheba G, Amadalo B (2000) *Tithonia diversifolia* as a green manure for soil fertility improvement in western Kenya: a review. Agrofor Syst 49:201–221

Kumar K, Goh KM (1999) Crop residues and management practices: effects on soil quality, soil nitrogen dynamics, crop yield, and nitrogen recovery. Adv Agron 68:197–319

Kurwakumire N, Chikowo R, Mtambanengwe F, Mapfumo P, Snapp S, Johnston A, Zingore S (2014) Maize productivity and nutrient and water use efficiencies across soil fertility domains on smallholder farms in Zimbabwe. Field Crop Res 164:136–147

Makkonen M, Berg MP, van Logtestijn RS, van Hal JR, Aerts R (2013) Do physical plant litter traits explain non-additivity in litter mixtures? A test of the improved microenvironmental conditions theory. Oikos 122:987–997

Makumba W, Akinnifesi F, Janssen B, Oenema O (2006) The long-term impact of a gliricidia-maize intercropping system on carbon sequestration in southern Malawi. Agric Ecosyst Environ 118:237–243

Motsara MR, Roy RN (2008) Guide to Laboratory establishment for plant nutrient analysis. FAO Fertilizer and Plant nutrition bulletin. Food and Agriculture Organization, Rome, p 219

Mucheru-Muna M, Mugendi D, Pypers P, Mugwe J, Kung'u J, Vanlauwe B, Merckx R (2014) Enhancing maize productivity and profitability using organic inputs and mineral fertilizer in central Kenya small-hold farms. Exp Agric 50:250–269

Nziguheba G, Merckx R, Palm CA, Rao MR (2000) Organic residues affect phosphorus availability and maize yields in a Nitisol of western Kenya. Biol Fertil Soils 32:328–339

Orwa C, Mutua A, Kindt R, Jamnadass R, Anthony S (2009) Agroforestree database: a tree reference and selection guide version 4.0. http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp. Accessed 22 June 2016

Ostrowska A, Porębska G (2015) Assessment of the C/N ratio as an indicator of the decomposability of organic matter in forest soils. Ecol Indic 49:104–109

Palm CA, Sanchez PA (1990) Decomposition and nutrient release patterns of the leaves of three tropical legumes. Biotropica 22:330–338

Palm CA, Gachengo CN, Delve RJ, Cadisch G, Giller K (2001) Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. Agric Ecosyst Environ 83:27–42

Partey ST, Thevathasan NV (2013) Agronomic potentials of rarely used agroforestry Species for smallholder agriculture in sub-Saharan Africa: an exploratory study. Commun Soil Sci Plant Anal 44:1733–1748

Partey ST, Quashie-Sam SJ, Thevathasan NV, Gordon AM (2011) Decomposition and nutrient release patterns of the leaf biomass of the wild sunflower (*Tithonia diversifolia*): a comparative study with four leguminous agroforestry species. Agrofor Syst 8:123–134

Partey ST, Preziosi RF, Robson GD (2012) Effects of organic residue chemistry on soil biogeochemistry: implications for organic matter management in agroecosystems. In: Adewuyi B, Chukwu K (eds) Soil fertility: characteristics, processes and management. Nova Publishers, New York, pp 1–28

Partey ST, Preziosi RF, Robson GD (2014a) Short-term interactive effects of biochar, green manure, and inorganic fertilizer on soil properties and agronomic characteristics of maize. Agric Res 3:128–136

Partey ST, Preziosi RF, Robson GD (2014b) Improving maize residue use in soil fertility restoration by mixing with residues of low C-to-N ratio: effects on C and N mineralization and soil microbial biomass. J Soil Sci Plant Nutr 14:518–531

Ragasa C (2014) Why Ghana lagged behind in maize productivity. IFPRI Ghana Strategy Support Program, Accra **(Draft report)**

Ragasa C, Dankyi A, Acheampong P, Wiredu AN, Chapoto A, Asamoah M, v R (2013) Patterns of adoption of improved maize technologies in Ghana. IFPRI, Accra **(GSSP Working Paper 34)**

Salas AM, Elliott ET, Westfall DG, Cole CV, Six J (2003) The role of particulate organic matter in phosphorus cycling. Soil Sci Soc Am J 67:181–189

Sistani KR, Adeli A, McGowen SL, Tewolde H, Brink GE (2008) Laboratory and field evaluation of broiler litter nitrogen mineralization. Bioresour Technol 99:2603–2611

Sommer R, Bossio D, Desta L, Dimes J, Kihara J, Koala S, Mango N, Rodriguez D, Thierfelder C, Winowiecki L (2013) Profitable and sustainable nutrient management systems for east and southern African smallholder farming systems—challenges and opportunities. http://www.ciat.cgiar.org/wpcontent/uploads/2013/06/profitable_and_sustainable_nutrient_management_systems.pdf. Accessed 8 Jul 2016

Starr F, Starr K, Lloyd Loope L (2003) *Acacia auriculiformis*. http://www.citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.608.2853&rep=rep1&type=pdf. Accessed 27 Jul 2016

Toth SJ, Prince AL (1949) Estimation of cation exchange capacity and exchangeable Ca, K and Na contents of soils by flamephotometric techniques. Soil Sci 67:439–445

Troeh FR, Thompson LM (2005) Soils and soil fertility, 6th edn. Blackwell Publishing Professional, New York, p 489

Vanhie M, Deen W, Lauzon JD, Hooker DC (2015) Effect of increasing levels of maize (*Zea mays* L.) residue on no-till soybean (*Glycine max* Merr.) in Northern production regions: a review. Soil Till Res 150:201–210

Xiang SR, Doyle A, Holden PA, Schimel JP (2008) Drying and rewetting effects on C and N mineralization and microbial activity in surface and subsurface California grassland soils. Soil Biol Biochem 40:2281–2289