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Research article

Contribution of organic inputs to maize productivity in the Eastern African region: A quantitative synthesis

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Abstract

Organic-inputs are largely viewed as a tool for improving soil fertility in low-input cropping systems, particularly in the Eastern African region (EAR). However, crop yield responses to organic-inputs are often highly variable; hence comprehensive information is crucial to support evidence-based input management decisions. Quantitative synthesis was conducted based on 330 paired-observations (derived from 33 papers representing 177 field trials from the EAR) to quantify how maize yield responds to sole-organic and combined (Org + NP) input additions across various moderating factors. On average, the overall yield increase relative to the unfertilized control was 103 ± 10% (95% confidence interval; CI) with sole-organic and 144 ± 12% (95% CI) with Org + NP addition. Sole-organic and Org + NP were significantly dependent on the soil type and organic-type categories with yield increases of 55–190% and 78–222%, respectively. Conversely, both input effects were not significantly influenced by the application rate or rainfall categories, yet only Org + NP effect was influenced by the site-productivity. Across the categorical factors, the highest yield difference was in Nitisols (2.2 ± 0.2 t/ha (95% CI) and the lowest in Andosols (1.1 ± 0.4 t/ha (95% CI). Sole-organic effects appeared to be comparable with Org + NP particularly for high-productivity sites, Andosols and high organic-input conditions. Generally, despite variations in the magnitude of yield benefits with soil-climate conditions, combined use stands out as a potential management strategy to improve productivity; while sole-organic inputs could be an alternative approach for resource-poor farmers with relatively infertile soils.

Introduction

Maize (*Zea mays* L.), the most important food crop in the Eastern African region (EAR), is grown in large parts of the region under a wide-range of soil and climatic conditions (Kornher, 2018). It plays a major role in the livelihoods of millions of smallholder farmers in Africa (Food and Agriculture Organization of the United Nations, 2015). Maize production in the EAR reached nearly 28 million t in 2016, accounting for about 40% of the total production of the continent, with the major share of maize production coming from Ethiopia (7.9 million t), Tanzania (5.9 million t), Kenya (3.3 million t), Zambia (2.9 million t), Uganda (2.7 million t) and Malawi (2.4 million t) according to the Food and Agriculture Organization Corporate Statistical Database (2016). Despite its importance and high yield potential (over 10 t/ha) with optimum management (Agegnehu et al., 2016), the maize yield for this region has remained below 2.0 t/ha (Food and Agriculture Organization Corporate Statistical Database, 2016). Low yields are associated with various biotic and abiotic factors, including soil fertility depletion due to continuous cropping without soil replenishment or inherent low fertility of the soils or

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both (Negassa et al., 2005; Omotayo and Chukwuka, 2009), adverse weather conditions (Yan et al., 2019) and rapid mineralization of soil organic matter without frequent addition of organic inputs (Oldfield et al., 2019).

The challenge of sustainably improving crop production in the EAR can be principally related to appropriate soil nutrient management practices. In humid and sub-humid areas, nitrogen (N) supply is a key limiting factor in crop production for the majority of farmers (Chianu et al., 2011; Food and Agricultural Organization of the United Nations and Daugherty Water for Food Institute, 2015). Soil phosphorus (P) deficiency is also widespread in the EAR (Sanchez, 2002; Akinnifesi et al., 2007; Omotayo and Chukwuka, 2009; Cobo et al., 2010). For example, 80% of the land held by small-scale owners in Western Kenya that is used for maize is extremely deficient in P (Sanchez, 2002). Many East African countries have an increasing need for mineral fertilizer to enhance crop yields (Food and Agricultural Organization of the United Nations and Daugherty Water for Food Institute , 2015), but most farmers are unable to afford the high prices of mineral fertilizers.

Besides their escalating price, mineral fertilizers even if used continuously cannot sustain crop yield on acidic and poorly buffered soils, but do aggravate the decline in soil pH and exchangeable cations (Hartemink et al., 1996), which in turn results in an overall reduction in soil and crop productivity. Thus, the use of organic-input technologies, either alone or combined with mineral fertilizers, has increasingly gained recognition in addressing soil fertility problems in low-input cropping systems, particularly in the EAR (Chivenge et al., 2009; Felix et al., 2012; Agegnehu et al., 2016). Such practices could potentially decrease the mineral fertilizer requirement for crop production, which in turn would reduce the cost of producing food, while simultaneously mitigating soil fertility and environmental pollution issues.

Organic resources such as farmyard manure (FYM), compost and cattle manure are widely used by stallholder farmers in the EAR as a substitute for or complement to mineral fertilizer additions (Mugwe et al., 2009; Bedada et al., 2014). For example, in the central highlands of Kenya, it has been reported that about 95% of smallholder farmers growing maize use FYM (Felix et al., 2012). Numerous site-specific studies have been conducted to examine how the maize yield responds to the addition of nutrient inputs either as sole-organic or in combination with mineral fertilizers (Negassa et al., 2005; Chivenge et al., 2009; Bedada et al., 2014; Agegnehu et al., 2016). These studies have demonstrated that the soil organic content (OC) and nutrient buildup and crop yield could be significantly influenced by the external organic and mineral inputs. However, the experimental results from these site-specific studies were highly variable, particularly regarding the maize yield. Regardless of these variations, the results from individual studies can be synthesized to reveal the central pattern of changes in crop yield induced by the external addition of organic/mineral inputs under varying agroecological scenarios (Sileshi et al., 2008). In this regard, however, comprehensive information is lacking on crop yield response to those organic inputs which are widely applied by farmers in the EAR. Largely, the growing amount of literature on site-specific studies on crop yield with and without inputs in the EAR has made it possible to synthesize results across studies and to reach an overall understanding. Therefore, using methods for combining data from various site-specific studies, we attempted: 1) to determine a regional estimate of maize yield response to sole-organic and combined (Org + NP) input additions in the EAR; and 2) to explore the effect of soil, climate and organic management factors on the magnitude of this yield response.

Materials and Methods

Literature inclusion criteria and data compilation

The data used in this study were mainly obtained through an exhaustive literature search of various electronic databases (using as keywords: organic amendments, integrated nutrient management, combined organic and inorganic inputs, manure, FYM, or compost, and maize yield), and subsequently by extending the search to the references found in these publications. The collected papers were then checked and screened to include only those papers that satisfied the following criteria: 1) originated from countries in the EAR; 2) included three treatments within a study, namely unfertilized-control, sole-organic and a combination of organic and inorganic NP inputs (Org + NP); 3) included at least one organic-input type (compost, FYM or cattle manure), and the same type of organic-input was applied in both the sole-organic and Org + NP treatments within the same trial for a specific site; 4) maize yield was reported for sole-organic, Org + NP inputs and the unfertilized control; and 5) conducted in an appropriate experimental design (randomized and replicated manner) under rainfed conditions. For the Org + NP criterion, the application of organic fertilizer served as a partial substitute for NP, commonly with half of the recommended NP rate as fertilizer and the other half as organic.

On the basis of these criteria, 33 papers (published between 1999 and 2016, and one unpublished data) were selected for inclusion in the analysis (Table 1). These papers consisted of 177 field trials from 60 study sites, representing the contrasting soil and climatic conditions of the EAR. Among these, 12 papers contained results from multi-locational trials (2–5 locations), 9 papers contained multi-seasonal results (3–10 cropping seasons) and 6 papers were from multi-locational and seasonal trials, while 11 papers consisted of results from a single location and season trials. Yield data were extracted and coded in a worksheet, and the resulting database contained 330 side-by-side yield observations for sole-organic, Org + NP and unfertilized-control plots (Table 2). In parallel to recording yield data from each study site, the following were documented: information about soil type, annual rainfall, organic-input characteristics (organic source, application rate). During data extraction, in cases where the yield data were presented only in graphical form, the information was extracted using the Graph Digitizer software (GetData Graph Digitizer, version 2.26) with a digitization error of less than 1%.

Table 1 Papers included in the analysis, showing the country where the study was conducted, organic-input types used, number of sites and seasons of the study

Author(s)	Location[†]	OIT[‡]	Number of sites	Number of seasons	Source
Achieng et al. (2010)	KEN	FYM	2	1	Agric. Biol. J. N. Am. 1: 740–747.
Adamtey et al. (2016)	KEN	FYM	2	3	Agric. Ecosyst. Environ. 235: 61–79.
Ademba et al. (2014)	KEN	FYM	1	1	African J. Agric. Res. 9: 1571–1578.
Admas et al. (2014)	ETH	Compost	1	1	Glob. J. Sci. Front. Res. 14: 1–11.
Bedada (2015)	ETH	Compost	1	5	PhD thesis, Swedish University of Agricultural Sciences.
Bedada et al. (2014)	ETH	Compost	4	6	Agric. Ecosyst. Environ. 195: 193–201.
Beyza (2014)	ETH	FYM	1	1	Afr. J. Agron. 2:194–199.
Bucagu et al. (2013)	RWA	Manure	1	1	Agric. Sci. 1(1):15–34.
Chemutai (2016)	KEN	FYM	1	2	M.Sc. thesis, University of Nairobi
Chivenge et al. (2009)	KEN	FYM	2	10	Agron. J. 101: 1266–1275.
Edwards et al. (2007)	ETH	Compost	1	6	FAO, Rome, Dec, 2007, pp. 1–55.
Endris and Jafer (2015)	ETH	Compost	3	1	J. Agron. 14: 152–157.
Habtamu (2015)	ETH	Compost	1	1	J. Agric. Soil Sci. 3: 68–78.
Jaime and Viola (2011)	MOZ	Compost	2	1	Proceedings, pp. 617–619.
Janssen (2011)	KEN	FYM	1	10	Plant Soil. 339: 3–16.
Kapkiyai et al. (1999)*	KEN	Manure	1	1	Soil Biol. Biochem. 31: 1773–1782.
Kisaka et al. (2015)	KEN	Manure	1	6	Exp. Agr. 52: 279–299.
Laekemariam and Gidago (2013)	ETH	Compost	1	2	Am. J. Plant Nutr. Fert. Technol. 3: 43–52.
Mucheru-Muna et al. (2007)	KEN	Manure	2	7	Agroforest. Syst. 69: 189–197.
Mucheru-Muna et al. (2013)	KEN	Manure	2	7	Exp. Agr. 50: 250–269.
Mugwe et al. (2007)	KEN	Manure	1	4	Afr. Crop Sci. J. 15: 111–126.
Mugwe et al. (2009)	KEN	Manure	1	4	Soil Use Manage. 25: 434–440.
Munyabarenzi (2014)	RWA	FYM	2	1	M.Sc. thesis, Kenyatta University.
Mutegi et al. (2012)	KEN	Manure	1	2	Sky. J. Soil. Sci. Environ. Manage. 1: 9–14.
Negassa et al. (2005)	ETH	FYM	4	1	Agric. Rural Dev. Trop. Subtrop. 106: 131–141.
Negassa et al. (2007)	ETH	FYM	1	3	Tropentag 2007 Conference, Witzenhausen, Frankfurt, Germany, pp. 1–8.
Ngwira et al. (2013)	MAL	Compost	3	4	Agroecol. Sustain. Food. 37: 859–881.
Oloo (2016)	KEN	Manure	1	2	J. Agric. Sci. Food Technol. 2: 35–40.
Omotayo and Chukwuka (2009)	KEN	Manure	1	1	Afr. J. Agric. Res. 4: 144–150.
Van Haute (2014)	KEN	Compost	5	1	M.Sc. thesis, Ghent University.
Whitbread et al. (2013)	MAL	Compost	1	1	Report; University of Göttingen, Germany.
Yackob et al. (2016)	ETH	Compost/Manure	1	2	Report
Zelalem (2014)	ETH	FYM	1	1	Afr. J. Agric. Res. 9: 663–669.
Zerihun et al. (2013)	ETH	FYM	1	2	Afr. J. Agric. Res. 8: 3921–3929.

[†] ETH = Ethiopia; KEN = Kenya; MAL = Malawi; MOZ = Mozambique; RWA = Rwanda; TAN = Tanzania.

[‡] OIT = organic-input type; FYM = farmyard manure.

[*] yield data only reported for an average of 18 season/year trials.

Table 2 Summary of data (mean ± SD) used in the analysis, number of observations and actual yield values for the unfertilized control, sole-organic and organic + NP inputs across the categorical factors

Categorical factor	*n*[†]	Inorganic NP (kg/ha)[‡]		Maize yield (t/ha)			Y_d (*p* value)[‡‡]	
		N	P	Org + NP	Organic	Control	Org	Org + NP
Site productivity							0.23	0.0003
Low (< 1 t/ha)	50	51 ± 26	31 ± 17	3.18 ± 1.6	2.66 ± 1.3	0.96 ± 0.3		
Medium (1–2 t/ha)	144	43 ± 24	46 ± 20	4.67 ± 1.2	3.76 ± 1.0	1.80 ± 0.6		
High (> 2 t/ha)	136	57 ± 28	36 ± 17	6.32 ± 1.4	5.47 ± 1.4	3.67 ± 1.1		
Soil type							0.006	<.0001
Ferralsols	22	58 ± 26	26 ± 20	4.98 ± 1.7	3.79 ± 1.2	2.20 ± 1.4		
Nitisols	103	51 ± 25	43 ± 18	5.15 ± 1.2	4.18 ± 1.4	2.02 ± 0.9		
Andosols	16	43 ± 3	24 ± 0.9	3.98 ± 1.8	3.52 ± 1.6	2.10 ± 1.1		
Mean annual rainfall (mm)							0.033	0.047
Low (< 700)	–	–	–	–	–	–		
Medium (700–1400)	69	49 ± 27	29 ± 14	5.48 ± 1.7	4.63 ± 1.6	2.37 ± 1.3		
High (> 1400)	246	54 ± 19	58 ± 10	4.58 ± 0.8	3.67 ± 1.1	1.96 ± 0.8		
Organic-input type							<.0001	<.0001
Manure	136	42 ± 25	48 ± 24	4.30 ± 1.4	3.58 ± 1.4	1.52 ± 0.7		
FYM	146	61 ± 26	44 ± 18	6.19 ± 1.4	5.25 ± 1.4	2.87 ± 1.4		
Compost	50	48 ± 21	22 ± 5	4.13 ± 1.8	3.36 ± 1.5	2.19 ± 1.4		
Organic-input rate (t/ha)							0.054	0.073
< 5	29	53 ± 14	56 ± 14	5.07 ± 1.6	3.95 ± 1.5	2.05 ± 0.9		
5–10	62	57 ± 27	43 ± 19	5.39 ± 1.9	4.23 ± 1.5	2.55 ± 1.6		
10–15	39	61 ± 28	31 ± 13	6.08 ± 2.3	4.68 ± 2.0	3.06 ± 1.9		
15–20	–	–	–	–	–	–		
> 20	29	33 ± 7	25 ± 4	4.62 ± 1.1	4.04 ± 1.5	1.98 ± 0.8		

[†] number of observations for mean yield data extracted from studies are same for treatment and control in each category as publications report side-by-side comparisons;

[‡] amount and proportion of mineral fertilizer (N and P) applied in combination with organic-input.

[‡‡] *p* values of the relative yield differences for sole-organic and combined input addition within each category;

– data not included due to insufficient reporting

Study categorization

In order to assess the effects of sole-organic and Org + NP additions across the studies, yield data were grouped into five categories based on site and organic-input characteristics information reported in the original studies. Description of these controlling factors with the number of observations is presented in Table 2. The soil productivity of each study site was identified based on the unfertilized-control maize yields. Accordingly, the yield dataset was grouped into three productivity classes: less than 1.0 t/ha (low), 1.0–2.0 t/ha (medium) and greater than 2.0 t/ha (high productivity sites), using the productivity score described in Sileshi et al. (2008). This grouping was based on the assumption that the crop yield from the unfertilized control reflected the potential of a particular study site and its management conditions (Wang et al., 2015). Considering the soil type of the study sites, the dataset was categorized into soil groups from the World Reference Base for Soil Resources (WRB) scheme (IUSS Working Group WRB, 2015). In cases where some studies reported the study site soils based on a different classification scheme, the soils were converted into the WRB soil group equivalents using Buol (2006).

Organic-inputs were categorized as compost, FYM and cattle manure. The dataset was also divided into three subgroups of organic-input rate application (less than 5 t/ha/y, 5–10 t/ha/y, 10–15 t/ha/y, 15–20 t/ha/y, greater than 20 t/ha/y). The amounts of N and P from mineral fertilizers applied in combination with organic input are listed in Table 2. Considering the long-term mean annual rainfall (MAR) of sites, the dataset was categorized into three rainfall classes: less than 700 mm (low), 700–1400 mm (medium) and greater than 1400 mm (high) based on the classification described in Sileshi et al. (2008). In the above categorizations, subgroups with fewer observations ($n < 10$) were excluded from the analysis (for example; low MAR, organic rate 15–20 t/ha/y). Moreover, studies were excluded that had not reported the site soil type, MAR or organic-input types or had reported the same soil type for a range of sites.

Determination of yield effect of inputs

In meta-analysis, an effect size is a value reflecting the magnitude of the experimental treatment effect compared to a reference group (Borenstein, et al., 2009). In the current study, two effect size estimators were computed for each observation (side-by-side comparison between sole-organic or Org + NP and control) for the categorical factors previously described. First, a response ratio (R) was calculated as the ratio of maize yield with sole-organic or combined addition (Y_t) to the unfertilized-control yield (Y_c). These values were converted and expressed as the percentage change of yield ($\Delta Y_{\%}$) from the unfertilized yield for ease of interpretation (Equation 1):

$$\Delta Y_{\%} = (R - 1) \times 100 \quad (1)$$

where R is the response ratio.

A second effect size estimator, called the absolute yield difference (Y_d), corresponded to the difference in maize yield (measured in tonnes per hectare) between sole-organic or Org + NP inputs and the unfertilized control plots (Equation 2):

$$Y_d = Y_t - Y_c \quad (2)$$

where Y_t is the maize yield with sole-organic or combined addition and Y_c is the unfertilized-control yield.

The absolute yield difference was used in this study as it reflects the actual yield gain from the external nutrient input management.

Statistical analyses

Mean effect sizes and 95% confidence intervals (CI) for a given categorical group were generated using RevMan (version 5.3; Cochrane; London, UK). When comparing categorical groups, mean effect sizes (for sole-organic or Org + NP) were considered to be significant if their respective 95% CIs did not overlap each another (Borenstein et al., 2009). The normality assumption was tested using normal quantile-quantile plots and verified graphically. To assess the effect of the categorical factors, a random-effects model with a hierarchical structure was developed using the MIXED procedures of the SAS software (version 9.1; SAS Institute Inc.; Cary, NC, USA). In addition, the distribution of the actual yield and Y_d for sole-organic or Org + NP inputs were determined for selected categorical factors.

Results

Overall yield distributions and responses

The cumulative distributions of maize yields (treatment and control) and Y_d with sole-organic and Org + NP input addition for the considered categorical factors are shown in Fig. 1. About 80% of the yield distributions (by pooling-up all categorical groups) were less than 3 t/ha for the unfertilized control, less than 6 t/ha for the sole-organic input and less than 6.8 t/ha for Org + NP input management (Fig. 1A). Similarly, the chance of achieving maize yields greater than 6.5 t/ha was low (less than 10%) with sole-organic input addition. Fig. 1B shows that about 80% of the distribution of Y_d values was 2.5–3.5 t/ha for Org + NP inputs, whereas it was 1.9–2.8 t/ha for sole-organic inputs. In Fig. 1D, the distributions of Y_d values for Org + NP inputs were similar for medium and high productivity sites. With sole-organic inputs, the probability of Y_d being less than or equal to 2 t/ha was about 95% for Andosols, and the same probability was determined for Nitisols exceeding 4 t/ha (Fig. 1E).

The overall maize yield (mean ± SD) across the categorical factors showed considerable variation, ranging from 0.96 ± 0.31 t/ha to 3.67 ± 1.09 t/ha in the unfertilized-control plots, 2.66 ± 1.31 t/ha to 5.47 ± 1.43 t/ha with sole-organic input, and from 3.18 ± 1.61 t/ha to 6.31 ± 1.37 t/ha with Org + NP input addition (Table 2). The yield responses were positively influenced by the addition of sole-organic and Org + NP inputs (Fig. 2). On average, the overall yield increase ($\Delta Y_{\%}$) over the unfertilized control was 103 ± 10% (95% CI) with sole-organic and 144 ± 12% (95% CI) with Org + NP addition (Fig. 2A). However, the magnitude of the impact varied depending on the site productivity, soil type, input type and climatic conditions as presented in the following sections.

Influence of organic-input type and application rate on yield response

The maize yield responses to both sole-organic and Org + NP additions varied significantly by the type of organic input (Fig. 2). The yield increase relative to the control was more pronounced when cattle manure was applied with NP-fertilizer (222 ± 29%) followed by FYM (158 ± 13%). Compost increased the yield by 78 ± 21% (95% CI) when applied alone and by 111 ± 18% (95% CI) when applied in combination with NP fertilizer (Fig. 2C). Yield differences (Y_d) for the sole-organic treatment also varied from the lowest (1.2 t/ha) with compost to the highest (2.1 t/ha) with FYM addition (Fig. 2D), and the later was even 16% greater than that of the combined use of compost with NP fertilizers. For the Org + NP treatment, the significantly highest Y_d (3.2 t/ha) was observed from FYM, followed by 2.8 t/ha and 1.9 t/ha from manure and compost addition, respectively.

The yield response was not significantly affected by the organic application rate (Fig. 3). A high application rate (greater than 20 t/ha) of sole-organic showed a slight increase in yield, but there was a decline with the application rate of Org + NP. At high rates, sole-organic addition resulted in yields closest to Org + NP (Fig. 3).

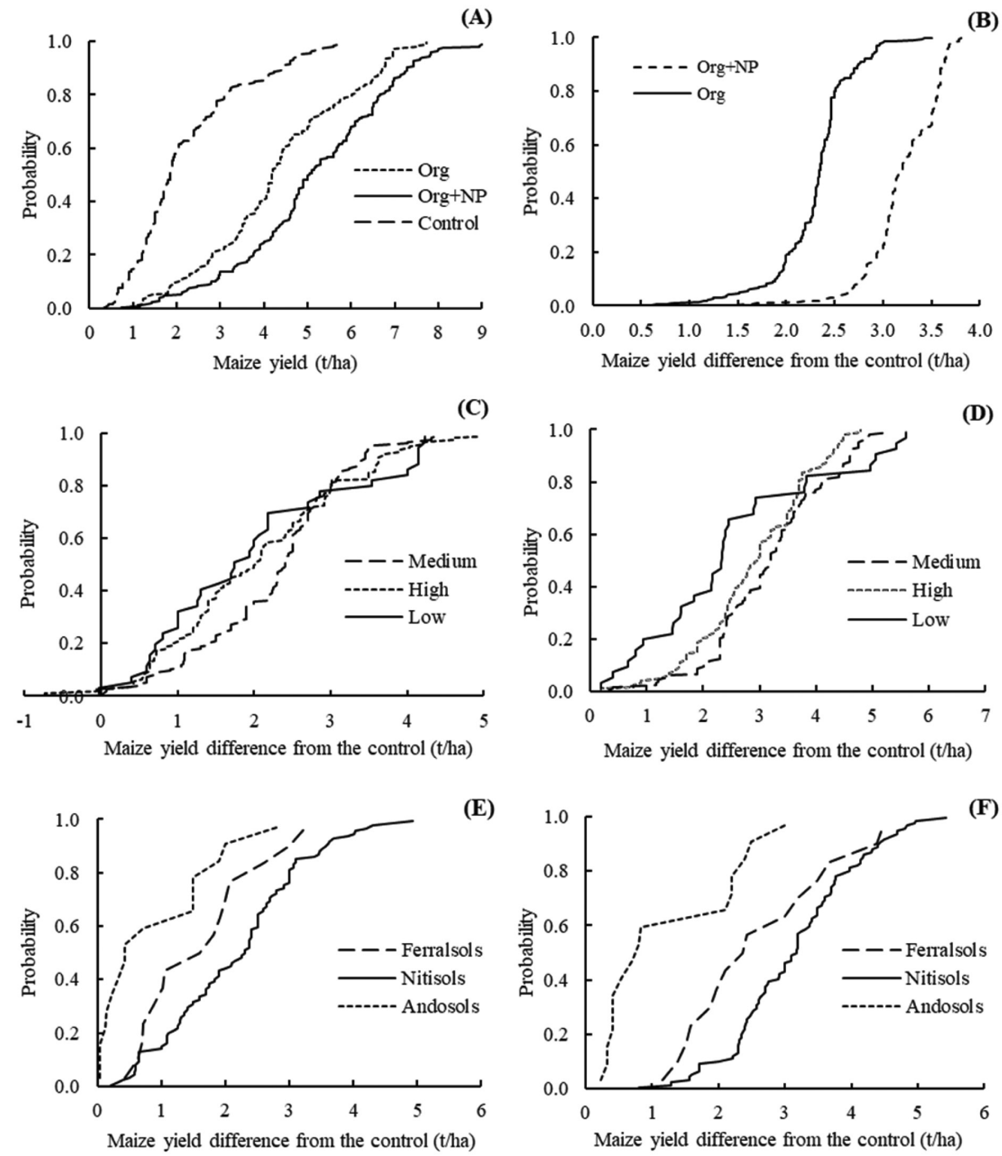

Fig. 1 Cumulative distribution of maize yield: (A) overall yield with input additions and control; (B) overall yield differences from unfertilized control; distribution of yield differences across site productivity class with (C) sole-organic (D) organic + NP inputs; distribution of yield differences across soil type with (E) sole-organic; (F) organic + NP inputs

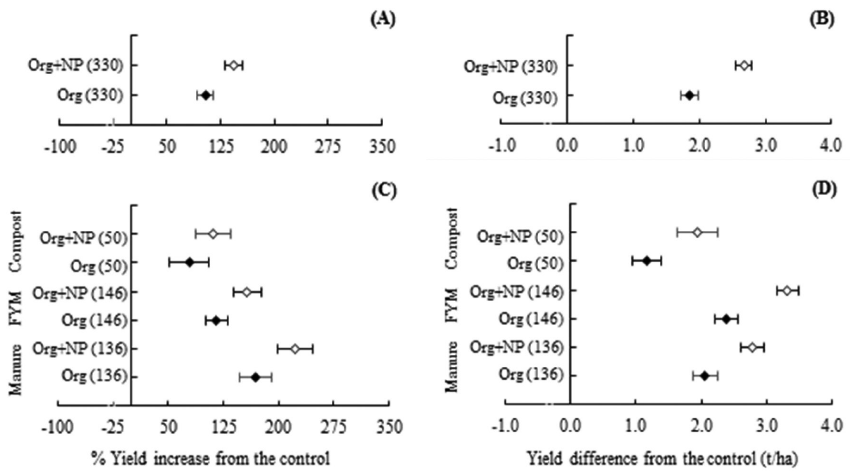

Fig. 2 Percentage yield increase and yield differences from the unfertilized-control due to sole-organic (Org) and combined (Org + NP) input application: (A) overall yield increase; (B) overall yield differences; (C) yield increase as influence by organic input types; (D) yield differences as influence by organic input types, where mean effect values are shown with 95% confidence intervals denoted by error bars and numerals in brackets on the y axis indicate number of observations in each group

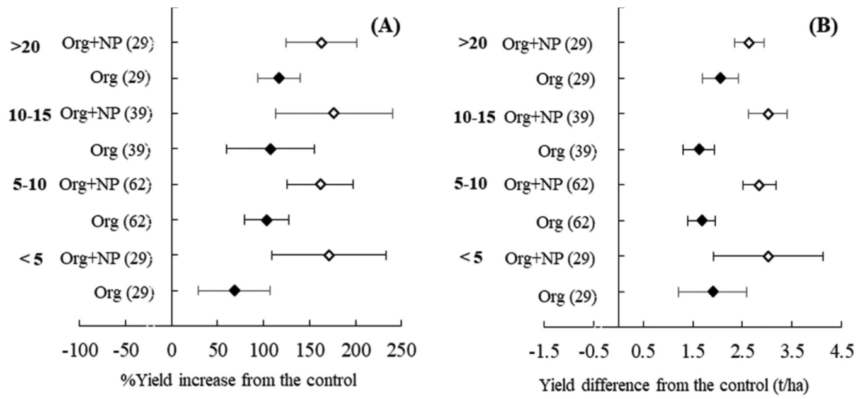

Fig. 3 Mean yield response to organic amendments relative to unfertilized control as influenced by application rates as: (A) percentage change; (B) yield difference, where mean effect values are shown with 95% confidence intervals denoted by error bars and numerals in brackets on the y axis indicate number of observations contributing to each mean; values in the y axis (< 5, 5–10, 10–15 and > 20) indicate rate of organic-inputs applied in t/ha/y

Influence of site productivity on yield response

The maize yield increment for sole-organic or Org + NP inputs over the control varied significantly with site productivity gradient. Greater yield increases for sole-organic (209%) and Org + NP (261%) inputs were observed on low productivity sites, whereas there was only a 54% increase for sole-organic and a 79% increase for Org + NP on high productivity sites (Fig. 4A). Despite the trend observed in the yield increase, Y_d for Org + NP input tended to increase with site productivity, in the range 2.2–2.9 t/ha (Fig. 4D); while it remained the same with sole-organic input (1.7–2.0 t/ha). Moreover, there was high variability in the yield increase and Y_d observed for both inputs on low productivity sites as indicated by the wider 95% CI bar.

Fig. 5 presents the distribution pattern of yield responses to each organic-input type across site productivity gradient. For all organic-input types, most of the data points with low control yields had high yield response values, but there was a consistent decline with increasing site productivity (Fig. 5A–D). A more than threefold (greater than 300%) yield increase relative to the unfertilized control was observed when manure (in 35% of the observations) and FYM (in 26% of the observations) were each combined with NP fertilizer on low to medium productivity sites (Fig. 5A–B). However, with sole-organic inputs, a threefold increase in yield occurred only on low productivity sites. The sole addition of FYM, cattle manure and compost inputs, more than doubled (greater than 200%) the maize yield relative to the unfertilized control in 40%, 53% and 11% of the observations, respectively. For compost, the yield increment of most (82%) of the data points was less than 56% on high productivity sites.

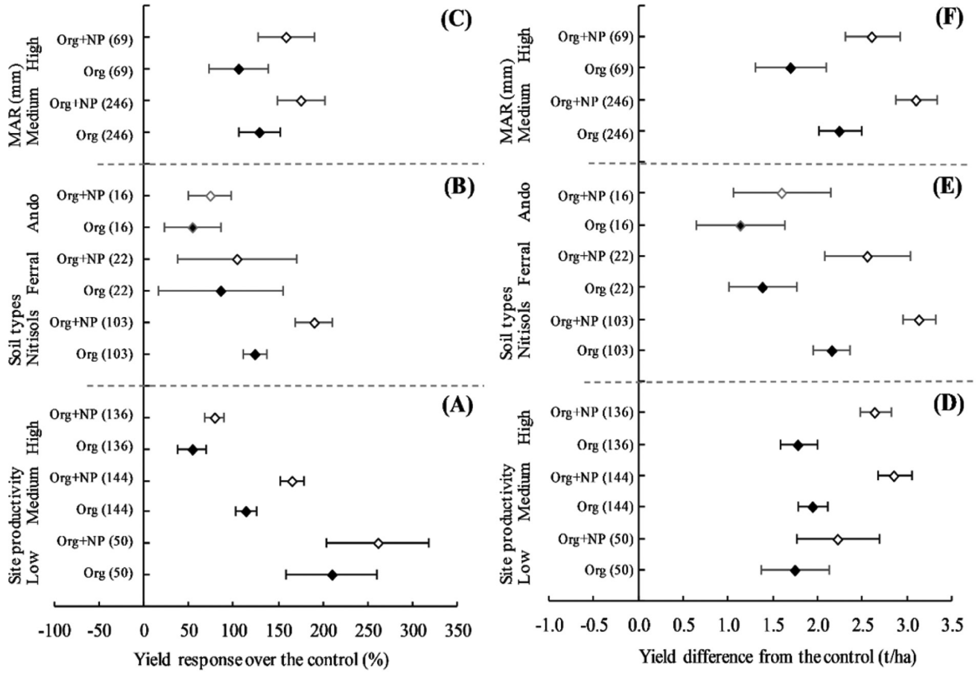

Fig. 4 Percentage yield increase (A–C) and yield differences (D–F) from the unfertilized-control due to sole-organic and combined (Org + NP) input application as influenced by: site productivity class; soil type; mean annual rainfall (MAR), where mean effect values are shown with 95% confidence intervals denoted by error bars and numerals in brackets on the y axis indicate number of observations in each group

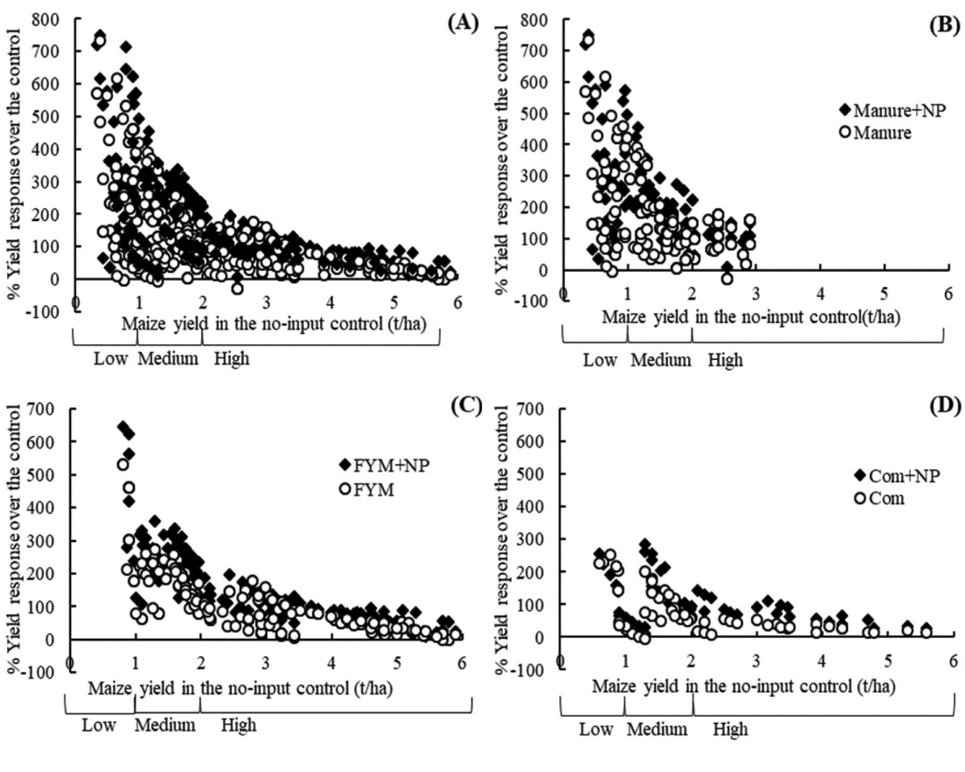

Fig. 5 Trend of maize yield increase with sole-organic and combined (Org + NP) inputs plotted against the unfertilized-control yield (t/ha), as categorized into organic-input types, across site productivity class (low, medium and high) which is indicated by the control yield: (A) overall; (B) cattle manure; (C) farmyard manure (FYM); (D) compost

Influence of soil type and annual rainfall on yield response

The yield increase over the unfertilized control was higher in Nitisols (124% for sole-organic and 190% for Org + NP) compared to 87% and 104%, respectively, in Ferralsols and 55% and 74%, respectively, in Andosols (Fig. 4B). The Y_d values had a similar trend to that of the yield increase, ranging from the highest mean (3.1 t/ha) in Nitisols to the lowest mean (1.1 t/ha) in Andosols. As shown by the wider 95% CI bars, variability in yield response was high in Ferralsols and Andosols (Fig. 4E). Furthermore, a value approaching zero indicated diminishing yield differences between the sole-organic input and the unfertilized control in Andosols. The Y_d value for Org + NP input was significantly high in Nitisols as the 95% CIs did not overlap with the other soil types.

The mean annual rainfall (MAR) of the study sites was also an important factor influencing the yield response for both sole-organic and Org + NP input additions. The MAR of the study sites ranged from 720 mm to 2,200 mm, with majority of observations (n = 75%) of yield data being for sites from medium MAR (701–1,400 mm) areas, while 21% were from high MAR (greater than 1,400 mm) areas. The maize yield response was higher for both sole-organic and Org + NP inputs when the MAR was in the range 701–1,400 mm and lower when the MAR was above 1,400 mm (Fig. 4C). Similarly, the Y_d value for sole-organic amendment differed from 1.7 t/ha for high MAR (greater than 1400 mm) area to 2.3 t/ha in medium MAR (701–1,400 mm) areas (Fig. 4F). The low yield response in high MAR areas might have been due to excess moisture and high leaching on high rainfall sites.

Discussion

The results clearly demonstrated the positive effects of organic inputs on maize yield either alone or in combination with mineral fertilizers, on low-input cropping systems in the EAR. However, the magnitude of the yield response to organic input depended on the site productivity class, soil type and organic-input type. Across the input types, cattle manure provided a greater yield increase compared to FYM or compost. This was partly explained by the quality of inputs (Berti et al., 2016). During analysis, the organic application rate was expected to be the major factor influencing the overall yield response. Unexpectedly, no significant effect was found with different application rates for either sole-organic or Org + NP input additions (Fig. 3). This could have been mainly due to: 1) potentially confounding effects of organic-input types (organic quality) as well as site productivity; 2) the high degree of variability in response values (wide confidence intervals) resulting from having relatively few observations (n = 29 for low and n = 29 for high application rates) as fewer observations contained amendment rate data to test this effect.

Greater maize yield responses from both sole-organic and combined addition were observed in Nitisols than in Ferralsols and Andosols. Such a remarkable yield gain in Nitisols could have been due to the fact that Nitisols are one of the most productive soils of the humid tropics (Janssen, 2011; Food and Agriculture Organization Corporate Statistical Database, 2015) and are known to have a deep, clay-rich subsoil which retains considerable amounts of plant nutrients and has a stable soil structure that permits deep rooting (IUSS Working Group WRB, 2015). However, large areas of Nitisols and Ferralsols in the EAR (mainly in Ethiopia and Kenya) have been depleted through continuous cultivation and erosion losses (Sanchez, 2002; Negassa et al., 2005; Cobo et al., 2010; Vanlauwe et al., 2009).

Conversely, the lower yield response observed in Ferralsols could be explained by their intense acidity and leaching, and by P-fixation (Hartemink et al., 1996) as these soils occur in humid-to-very-humid regions. Yield declines for maize under unfertilized conditions have been attributed to poor crop establishment due to soil acidity and nutrient deficiencies (Negassa et al., 2005; Chivenge et al., 2009; Mugwe et al., 2009; Mucheru-Muna et al., 2013). Furthermore, the lowest yield attributed to Andosols might have been due to their considerable capacity to render P unavailable to plants, while the lack of OM and N are problems associated with low MAR. Andosols develop on volcanic ash, and are the predominant soils along the East African Rift Valley in Ethiopia, Kenya and Rwanda under semi-arid conditions (IUSS Working Group WRB, 2015).

Site productivity, as indicated by the unfertilized-control yield, was also largely influenced by the performance of sole-organic and combined input additions. Compared to the unfertilized control, the yield increases for both the combined and sole-organic inputs were greater than 209% on low productivity sites, while the yield went below 54% and 78%, respectively, on high productivity sites (Fig. 4A). With combined input, more pronounced Y_d values (greater than 2.6 t/ha) were observed on the medium and high productivity sites (Fig. 4D), but sole-organic inputs showed only slight variation across the site productivity gradient. The trend observed for sole-organic inputs was inconsistent with the findings of Sileshi et al. (2008) who reported low maize yield responses to green manure across site productivity, which was almost the same as the maize yield of the unfertilized treatment.

The analysis of available data shows that sole-organic yields are typically lower than Org + NP yields in most circumstances. However, sole-organic practices can nearly match Org + NP yields on low productivity sites, Andosols and under high organic-input rate conditions. This can be profitable for low-input cropping systems (particularly in the EAR) where the use of mineral fertilizers has remained very low (average application rate = 8 kg/ha/y; Bedada, 2015) because most farmers are unable to afford them (Chianu et al., 2011). On the other hand, superior yield benefit achieved from combined addition can be explained by the synergistic effects of combined addition resulting in improved synchronization of nutrient release and uptake by crops which contributes to a high yield return (Mucheru-Muna et al., 2007; Chivenge et al. 2011).

In summary, this synthesis has provided evidence that combining organic-inputs with reasonable amounts of mineral fertilizers could improve the maize yield and decrease the demand for mineral fertilizers in the EAR. Alternatively, sole-organic input appears to be comparable with Org + NP yields, particularly on low productivity sites, Andosols and under high organic-input conditions, and hence resource-poor farmers should consider application of locally available organic sources. Such action can subsequently maintain and enhance the soil OC buildup and nutrient balances, as soil N and P deficiency is widespread in the region. The results also underline that optimal management strategies need to recognize and consider the soil-climate factors in promoting cost-effective and environmentally sound alternative practices for more sustainable agricultural productivity in the EAR. Nevertheless, one limitation of this analysis was that the duration of organic-input management was not considered due to insufficient data, as most of these studies did not capture long-term yield trends. The data presented for the analysis were dominated by studies of less than three years. As yield responses may differ depending on the duration and amount of organic inputs applied annually, further efforts should explore the long-term residual effects of these input management practices.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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