Effects of combined application of organic amendments and fertilizers on crop yield and soil organic matter: an integrated analysis of long-term experiments

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Abstract

A comprehensive synthesis of 32 long-term experiments in China is performed by comparing yields and SOM contents and their time by nutrient management responses (TNMR) to determine whether and to what extent combined application of organics amendments and fertilizers (organics+fertilizers) can increase productivity and soil organic matter (SOM) content and enhance the sustainability of diverse cropping systems. TNMR is defined as percentage changes over time in yields and SOM contents in external nutrient input treatments relative to initial and control plots and represents the net effects of nutrient management strategies on yields and SOM contents. Organics+fertilizers significantly increased yields over three crops (wheat, maize and rice) on average by 29% relative to sole organics and 8% to fertilizer only. Higher TNMR values in yields were found with organics+fertilizers in the sequence wheat (53%) > maize (40%) > rice (8%). Significant and positive time trends in TNMR of organics+fertilizers in wheat and maize yield may imply enhanced sustainability of cropping systems. Addition of organics (alone or combined with fertilizers) increased SOM contents and their TNMR over fertilizers applied alone. However, benefits varied between organics and organics+fertilizers by land use type. The latter led to higher SOM contents than (for dry land) and similar to the former (for dry-flooded and flooded systems). 2.3 and 1.4 times higher TNMR of organics+fertilizers in SOM content in dry land than dry-flooded and flooded systems implies that dry land was more responsive in SOM content increase upon adoption of organics+fertilizers than the latter. Overall, despite variation in the quantitative magnitude in crop or land use type, compared with application of

organics or fertilizers only, a combination of both represents the most effective way to produce more food, build up SOM and enhance sustainability, especially in dry land cropping systems.

Introduction

Intensification of crop production over the last 50 years has come to be known as the ‘green revolution’ and has proved to be very successful. This, combined with increased soil productivity, has allowed China to feed 22% of the global population using only 7% of the global arable land area (Zhang et al., 2011; Fan et al., 2013). However, environmental degradation resulting from excessive application of fertilizers has led to the development of more integrated approach to farming and plant nutrient management (Tilman, 1998; Fan et al., 2012; Chen et al., 2014).

Recycling of agricultural organics is an old but relevant and increasingly popular technology for maintaining soil productivity and saving fertilizers in response to the search for cost-effective nutrient management (Rasmussen et al., 1998; Fan et al., 2012; Misselbrook et al., 2012; Rosegrant et al., 2014). However, application of organics alone usually results in lower crop productivity levels than application of fertilizers (Trewavas, 2001; Seufert et al., 2012). The combined application of organic amendments and fertilizers (organics+fertilizers) has been gaining increasing recognition as a feasible and practical approach in boosting crop yields in the short term and enhancing soil organic matter (SOM) in the long term (Morris and Winter, 1999; Palm et al., 2001; Vanlauwe et al., 2001a,b; Dawe et al., 2003; Zhang et al., 2009; Diacono and Montemurro, 2010; Chivenge et al., 2011; Zhang et al., 2012; Liang et al., 2012; Yan et al., 2012). However, the extent to which the benefits in increased productivity and enhanced SOM across diverse cropping systems can be realized remains to be determined.

It is widely accepted that long-term cropping experiments (LTEs) remain the only reliable source of information in evaluating sustainable agricultural management systems and predicting future trends (Rasmussen et al., 1998; Dobermann et al., 2000). Since the 1980s numerous LTEs have focused on different cropping systems within China and have formed the basis of studies assessing crop productivity and SOM of various nutrient management strategies (Xu et al., 2006; Zhao et al., 2010; Zhao et al., 2012). However, most studies have been restricted to the locations of the field experiments with few synthesizing the information on a national scale. A comprehensive analysis nationally will offer important advantages including overcoming limited (or absence of) replication by using years and/or sites as a substitute for true replication and conducting comparison between different cropping systems. Furthermore, the methods used often compare the absolute values and/or dynamic changes in yields and SOM among treatments. This approach, however, does not take into consideration changes in measurements over time in the absence of external nutrient applications and the impact of changes in other management factors (e.g. tillage, crop variety and management) and biophysical factors such as climate change. This may mask the net effects and the contribution of organics+fertilizers to crop productivity and SOM.

Organics and fertilizers bring different advantages to soil management; a combination of both may lead to positive interactive effects in crop productivity (Vanlauwe et al., 2001b). However, added benefits of organics+fertilizers on cereal yields in Chinese LTEs remain to be tested.

Here, a comprehensive synthesis of the current scientific literature on Chinese LTEs at

national scale is conducted in an attempt to understand to what extent organics+fertilizers can increase productivity and SOM and enhance the sustainability of diverse cropping systems. The specific objectives were to determine the yields and SOM contents of various cereal cropping systems or land use types in both absolute terms and changes relative to initial values and in controls upon application of organics, fertilizers and organics+fertilizers at application rates representing best local practices, and the added benefits of organics+fertilizers on grain yields.

Materials and methods

Data sources

We have included all the available long-term data from 32 long-term experiments conducted throughout China. The experiments range in duration from 13 to 31 years and represent a wide range of climatic zones, soil types, cropping systems, and management practices. Detailed location information is presented in Appendix Table 1 in the online supporting information. Cropping systems involved are wheat–maize, wheat-rice and rice-rice double cropping, rice-based triple cropping, and wheat or maize single cropping, representing the major high productivity cereal-based cropping systems in the country. In total they account for 95% of total wheat, 64% of maize, and 90 % of rice production. The nitrogen (N), phosphorus (P) and potassium (K) inputs from fertilizers and N from organics are listed in Appendix Table 1. Crop, water and pest management followed the best local recommendations but differ among sites. Further details on the management and sampling

procedures used are given in the publications referring to the specific locations.

All long-term studies that met the following criteria were included.

1. The experiments included at least one cereal crop (wheat, maize or rice).
2. The same type of organics was applied in both the organics only and organics+fertilizers treatments within the same experiment. Organics used in current LTEs are manures, straw, green manures or composts.

3. At least three of the following treatments were included within a study: control, organics, fertilizers and organics+fertilizers. Fertilizer treatments comprised applied chemical NPK plots. In organics+fertilizers, application of organics served either as a supplement to the fertilizer NPK in most of LTEs, or as a partial substitute for NPK, usually with half of the recommended N rate as fertilizer and the other half as organics (e.g. in 6 LTEs). However, there were no experiments which included treatments in which NPK rates were the same in the fertilizers, organics and organics+fertilizers treatments. In cropping systems with more than one crop grown each year, organics were applied once a year (9 sites) or to both crops (13 sites). Control treatments received neither organics nor fertilizers. However, control plots received the same control measures in terms of weeds, insects and diseases, and supplemental irrigation as external nutrient input treatments (organics, fertilizers, and organics+fertilizers).

4. The same soil sampling methods to the same depths and the same methods for determination of SOM/C concentrations were used across all treatments within a study. The SOM/C data are reported as concentrations based on soil weight, e.g. g kg^{-1} or percentage (%). A conversion factor of 1.742 was used to convert SOC data to SOM.

Data grouping

All the datasets were divided according to cropping systems for crop yield analysis: winter wheat in north and northwest China and the Yangtze River Basin in east China, maize in north and northeast China, and rice in the Yangtze River Basin and south China; and land use type for SOM content analysis: dry, dry-flooded, and flooded systems. It should be noted that dry lands are represented as winter wheat-summer maize rotation systems on the North China Plain, wheat (or maize) cropping systems in the northwest and maize (or wheat and soybean) cropping systems in northeast China. Dry-flooded systems include rice-wheat/barley rotation systems in the Yangtze River Basin. Flooded systems are dominated by single, double or triple rice systems. Seventeen, ten and eight of the experiments involved wheat, maize, and rice, respectively, and thirteen, six and six were dry, dry-flooded and flooded systems.

Data manipulation

We first compared mean crop yield and SOM content in absolute terms among control, organics, fertilizers and organics+fertilizers plots across all land use types. Then the percentage changes in crop yield and SOM content in external nutrient input treatments relative to initial and control plots, referred to as time by nutrient management response (TNMR), were further compared using Eq 1.

$$TNMR = \left[(A_{f-fertilized} - A_{i-fertilized}) \div A_{i-fertilized} \right] \times 100 - \left[(A_{f-control} - A_{i-control}) \div A_{i-control} \right] \times 100 \quad \text{Eq 1}$$

A_f -fertilized and A_f -control represent the yield or SOM content in each year for external nutrient input treatments and controls since the second year of experiment started, while A_i -fertilized and A_i -control denote the initial data for yield or SOM content for external nutrient input treatments and controls in the first year, respectively.

In the TNMR approach both initial (baseline) values of external nutrient input treatments and long-term changes in SOM content and yield when neither organics nor fertilizers was applied are taken into consideration (Ladha et al., 2011). Thus, TNMR, which eliminates or minimizes the effects of other crop and soil management practices and climatic changes, reflects the net effects of different nutrient management strategies on changes in yield and SOM content. The TNMR also represents the cumulative residual effects of external nutrient inputs. Thus time trends in agronomic productivity or SOM, which can be positive, no change or negative, reflect to what extent sustainability of cropping systems will be enhanced by different nutrient management strategies.

We then quantified the added benefits in yield of organics+fertilizers by noting the interactive effects of organics+fertilizers on crop yields which were calculated according to Vanlauwe et al. (2001b) using Eq 2.

$$\text{Interactive effect (kg ha}^{-1}\text{)} = (A_{com} - A_{ck}) - (A_{fert} - A_{ck}) - (A_{or} - A_{ck}) \quad \text{Eq 2}$$

A_{ck} , A_{or} , A_{fert} , and A_{com} refer to yields in the controls and organics, fertilizers, and organics+fertilizers treatments, respectively. The interactive effect can be positive, negative, or zero. In the current study the interactive effects of organics+fertilizer were evaluated using the mean yield value for each crop over selected LTEs, in which chemical fertilizer rates

were the same in the fertilizers and organics+fertilizers treatments (Appendix Table 1).

Statistical analysis

A total of 32 long-term experiments located throughout the major climatic zones of China were involved in the assessment. The measurements were made at different sites over various time periods which constituted unbalanced data points in yield and SOM. Therefore a linear mixed model containing both fixed effects and random effects representing an extension of the traditional linear model and most suitable for analyzing unbalanced datasets was chosen to test the effects of nutrient management strategy and year on the yield and SOM content.

In the current study the SAS linear mixed model was fitted as a random intercept model. Yield and SOM in their absolute values and TNMR is the outcome variable. Nutrient management strategy (i), year (j) and location (k) are independent variables. Nutrient management strategy and year are fixed effects; Location is random effect. The linear mixed model is expressed by the following forms:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_{ijk}$$

Where, α_i , β_j and γ_k represent the nutrient management strategy, year and location effects, respectively. δ_{ijk} is random error.

Based on least squares mean of each treatment, multiple comparisons between treatments were made using Tukey–Kramer adjustment. Linear regression was used to evaluate the TNMR trend with time. Factors tested were considered to be statistically significant at $p < 0.05$. All analysis was performed using the SAS version 9.2 statistical package (SAS Institute,

2008).

Results

Comparison of actual yields and SOM contents

Table 1 gives the mean values of wheat, maize and rice yields across land use types as estimated by mixed models. Long-term external nutrient application significantly increased the mean grain yield of each crop compared with the control. Yield increased on average by 95, 62 and 109% after treatment with fertilizers alone, organics alone and organics+fertilizers, respectively, across the three cereal crops compared with the controls. Organics+fertilizers led to significantly higher grain yields than either fertilizers or organics applied alone in the case of all crops with the exception of fertilizers applied to maize. Organics alone led to the lowest grain yields with significant differences found for wheat and rice.

Similar to crop yields, long-term external nutrient application significantly increased SOM contents across the different experiments for each land use type compared with the control plots (Table 2). Across all land use types external nutrient addition increased SOM content on average by 8% for fertilizers alone, 18% for organics alone, and 23% for organics+fertilizers compared with the controls. Application of organics, either alone or in combination with fertilizers, led to higher SOM contents than fertilizers alone, with significant differences observed on dry and dry-flooded land. On dry land a significantly higher average SOM content was also found for the organics+fertilizers than application of organics alone.

Time by nutrient management response (TNMR) in yield and SOM content

Across the three cereal crops, organics+fertilizers led to the highest increases in crop yield response (Table 3). This was especially true for wheat crops, with TNMR values of 53 % for organics+fertilizers, 44 % for fertilizers alone and 32 % for organics. In maize the TNMR in yield followed the order organics+fertilizers > organics > fertilizers, with a significant difference observed between organics+fertilizers and fertilizers alone (Table 3). In contrast to wheat, no significant difference in TNMR in yield between organics+fertilizers and organics alone was observed for rice. Generally, TNMR values in yield for rice were lower than those in wheat or maize (Table 3). In contrast to wheat and maize, no positive TNMR trends in yield over time for rice were found (Fig. 1).

The TNMR trends of SOM content of each nutrient management strategy over time for all land use types were not significant (data not shown). However, increases in SOM response were evident following the input of organics either alone or combined with fertilizers, and on average over all land use types were 26% for organics alone, 29% for organics+fertilizers, and 12% for fertilizers alone (Table 4). There were no differences in average TNMR between organics and organics+fertilizers on dry or dry-flooded land, but organics+fertilizers led to significantly higher TNMR in SOM content (24%) than organics alone on flooded land (12%). The mean TNMR in SOM content over the three nutrient management systems followed the order dry land (25.6%) > flooded (16.7%) > dry-flooded (10.8%) (Table 4).

Added yield benefits of combined application of organics and fertilizers

Added benefits in terms of extra grain yield generated in organics+fertilizers treatments, which were calculated by assessment of interactive effects based on selected long-term experiments, averaged -551.9 kg ha⁻¹ for wheat, -2623.5 kg ha⁻¹ for maize and -844.3 kg ha⁻¹ for rice, the added benefit for all crops was - 882.2 kg ha⁻¹ (Table 5).

Discussion

Crop yield and management strategy

Results from our comparison of actual mean yield clearly highlight the yield benefits realized upon the external addition of nutrients in LTEs in the following order: organics+fertilizers > fertilizers > organics > control (Table 1). Yields in plots receiving organics increased on average by up to 62% across all experiments relative to the controls, and yields under organics alone were 17% lower than those in plots receiving fertilizers (Table 1). Thus, the results confirm that an attempt to establish a crop production system relying exclusively on organic nutrients as a tool in sustainable food production would not produce enough grain to meet the food demand (Seufert et al., 2012; Chivenge et al., 2011). However, it should be noted that the sole use of organics could result in substantial yield increases but only if these were available in sufficiently large quantities. Yields in organics+fertilizers were higher by 29 and 8% than those in organics only and fertilizers alone treatments, respectively. Nevertheless, in contrast to expectation, combining both types of inputs did not lead to added benefits in terms of added grain yields (Table 5).

Using the TNMR ratio approach which takes into consideration differences in the initial (baseline) values of external nutrient addition practices and controls and eliminates or minimizes the effects on yield of other crop and soil management practices and climate change (Ladha et al., 2011), we found that organics+fertilizers resulted in greater increases in yield response than application of either organics or fertilizers only (Table 3). TNMR differed significantly among crops in the sequence wheat (53%) > maize (40%) > rice (8%) (Table 3). Positive trends in TNMR in yield of organics+fertilizers over time for wheat and maize (Fig. 1) may imply enhanced sustainability of cropping systems and may be attributed to increased nutrient supply capacity and ‘organic matter impacts’ that may include gradual increases in SOM content and changes in soil physical properties (Myers et al., 1994; Palm et al., 2001; Merckx et al., 2001; Vanlauwe et al., 2001a; Zingore et al., 2008; Johnston et al., 2009). It should be noted that organics and fertilizers alone can also lead to positive TNMR in yield trends over time for wheat and maize (Fig. 1). However, the benefits of positive TNMR trends in yield were discounted by the lower yields and mean TNMRs in the organics or fertilizers application only compared to organics+fertilizers.

Both mean TNMRs in yield of organics and organics+fertilizers for rice were higher than those in fertilizer treatments (Table 3). However, neither fertilizers nor organics or organics+fertilizers treatments showed positive TNMR trends in yield over time in rice crops (Fig. 1). The latter is similar to the earlier argument that application of either manure or straw does not increase grain yield trends in rice-rice and rice-wheat cropping systems in Asia (Dawe et al., 2003). The absence of “organic matter impacts” seems the most likely

explanation for this. It is assumed that soil structure and aggregate stability, which was destroyed during land preparation, could be less important to the productive capacity of the soil in flooded systems.

Soil organic matter content and management strategy

The application of fertilizers alone led to a significantly higher mean SOM content in absolute terms than in the controls, with 19.3 g kg⁻¹ for dry, 28.3 g kg⁻¹ for dry-flooded, and 26.4 g kg⁻¹ for flooded systems (Table 2). Using TNMR the increase in response in SOM content following fertilizer applications was 13% for dry, 15% for flooded, and 3% for dry-flooded soils (Table 4). As the use of fertilizers led to an increase in crop yield (Table 1), an increase in C input to the soil was expected because this is a key driver for increased SOM (Glendining and Powlson, 1995; Tian et al., 2013). The results obtained here support the conclusions of Powlson et al. (2010) and Ladha et al. (2011) who argue that the long-term use of fertilizers leads to a slower decrease, and possible an increase, in SOM compared with control plots. Under organics we found that the SOM content in absolute terms (Table 2) and TNMR (Table 4) showed significantly higher increases in dry land and dry-flooded systems and similar values to fertilizer treatments in flooded systems.

Organics+fertilizers led to higher SOM contents and TNMR than (for dry land) or similar to those of organics alone (e.g. in dry-flooded and flooded systems, Table 4). The increased SOM responses under organics+fertilizers may be attributed to an increase in external organic C inputs (Johnston et al., 2009; Diacono and Montemurro, 2010; Zhang et al., 2010; Fan et al.,

2013; Maillard and Angers, 2014). In addition, in cases where greater SOM contents followed the organics+fertilizers treatments than either organics or fertilizers alone may also be attributed to increased root growth associated with additional C inputs from roots (Goyal et al., 1992; Jiang et al., 2014).

In the current study flooded soils had higher SOM contents on average than dry land across all treatments (Table 2). This can be due to increased C inputs (Kogel-Knabner et al., 2010; Tanji et al., 2003) in combination with flooded conditions that lead to a slower rate of decomposition of plant material resulting from a lack of O₂ (Neue et al., 1997; Sahrawat, 2004). However, in contrast to Ladha et al. (2011), dry-flooded systems showed higher SOM contents than flooded or dry land in the present study (Table 2), possibly because our long-term experiments in dry-flooded systems were located on fertile soils with higher initial SOM contents.

As dry land develops inherently low SOM contents the soils become more responsive to fertilizers or organics (applied alone or in combination with fertilizers). In terms of organics+fertilizers, TNMR values of dry land in SOM content were 2.3 and 1.4 times higher than dry-flooded and flooded systems, respectively (Table 4). Greater SOM build-up on dry land in the long term also implies larger increases in crop yield responses and crop system sustainability.

The limitations of the current study

Owing to weaknesses in the design of the existing LTEs (Dawe et al., 2003; Zhao et al., 2010) we cannot rule out some uncertainty in the current assessment. The main source of uncertainty is due to none of LTEs reviewed here including a treatment in which total NPK rates were the same in the fertilizers, organics and organics+fertilizers treatments. In almost all LTEs, total NPK inputs in organics + fertilizers were higher than in either organics or fertilizers application only. Thus, it is possible that the benefits especially in yields of organics + fertilizers could be over-estimated. On the other hand, none of the LTEs was designed with adjustment of chemical NPK rates depending on the rate of nutrient release from various quality organics to maintain appropriate nutrient concentrations in the root zone, so that the supply capacity of N or other nutrients may be over- or under-used. This would prevent crops from exhibiting their biological potential in maximizing agronomic productivity (Zhang et al., 2012). The absence of added benefits in terms of extra grain yield for organics+fertilizers treatments (Table 5) may provide indirect support for this hypothesis. The latter indicates the need for advanced management systems in organics+fertilizers toward yielding added produce while minimizing losses and maximizing input use efficiencies.

Conclusions

In general, application of organics + fertilizers was found to be the most effective way to produce more food, build up SOM and enhance the sustainability of cropping systems. Benefits varied by crop species and land use type. Greater TNMR values were found using

organics + fertilizers in the sequence wheat (53%) > maize (40%) > rice (8%). In contrast to rice, the TNMR of organics + fertilizers also showed significant and positive trends over time for wheat and maize. Dry land was more responsive in SOM content increase with combined organics and fertilizers than dry-flooded or flooded systems. However, absence of added yield benefits in organics + fertilizers signifies the need for further research on appropriate management techniques.

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Appendix Table S1. Supplementary data.

Supplementary data associated with this article can be found in the online version.

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Table 1 Mean yields of wheat, maize and rice under different nutrient management strategies of long-term experiments in China.

Treatment	Wheat		Maize		Rice		All crops	
	(kg ha ⁻¹)							
Control	17*	1384±243d†	10	3792±525c	11	3570±224d	38	2679±301d
Organics	11	2966±249c	5	6965±520b	7	4662±239c	23	4345±305c
Fertilizers	17	4016±241b	10	7364±523ab	11	5594±226b	38	5211±301b
Organics+fertilizers	16	4332±244a	9	7664±525a	11	6186±219a	36	5606±299 a

*Refers to numbers of long-term experiments involved in the analysis; †Data derived from mixed models are shown as average ($\pm$ std deviation); Different letters within each crop indicate significant difference among treatments at the 5% level of significance.

Table 2 Mean soil organic matter (SOM) contents under different nutrient management strategies for various land use types of long-term experiments in China.

Treatment*	Dry land		Dry-flooded land		Flooded land		All land	
	(g/kg)							
Control	13*	17.6±3.44 d†	6	26.4±2.73 c	6	24.2±2.84 c	25	21.4±2.10 d
Organics	8	21.4±3.45b	5	30.4 ±2.73a	2	27.1±2.84 ab	15	25.2 ±2.10b
Fertilizers	13	19. 3±3.44c	6	28.3±2.73 b	6	26.4±2.94b	25	23.2±2.11 c
Organics+fertilizers	12	23.1±3.44 a	5	30.5±2.73 a	6	28.4±2.84a	23	26.4±2.11 a

*Refers to numbers of long-term experiments involved in the analysis; † Data derived from mixed models are shown as average ($\pm$ std deviation); Different letters within each land use type indicates significant difference among treatments at the 5% level of significance.

Table 3 Mean time by nutrient management response (TNMR) of wheat, maize and rice yields of long-term experiments in China.

Treatment*										
	Wheat		Maize		Rice		All crops			
	(%)									
Organics	11*	32.1±9.7c†	5	35.5±7.4 ab	7	7.2 ±3.9a	23	25.2 ±5.3b		
Fertilizers	17	43.8±9.6 b	10	31.2±7.0 b	11	1.3 ±3.7b	38	28.6±5.2 b		
Organics+fertilizers	16	52.5±9.5a	9	39.5±7.0 a	11	7.5±3.7 a	36	36.3 ±5.2a		

* refers to numbers of long-term experiments involved in the analysis; †Values are means derived from mixed models are shown as average (±std deviation); Different letter within each crop indicates significant difference among treatments at the 5% level. TNMR is defined as the percentage change in yield in external nutrient input treatments relative to initial values and control plots.

Table 4 Mean time by nutrient management response (TNMR) of soil organic matter (SOM) contents for various land use types of long-term experiments in China.

Treatment	Dry land		Dry-flooded Land		Flooded land		All Land	
	(%)							
Organics	8*	30.2±4.8 a	5	14.7±3.6 a	2	11.5±8.6 b	15	26.2±3.0 a
Fertilizers	13*	12.8±4.6 b†	6	3.1±3.5 b	6	14.5±8.0 b	25	11.8±2.8 b
Organics+fertilizers	12	34.3±4.7 a	5	14.7±3.4 a	6	24.2±8.0 a	23	29.3 ±2.9a

* Refers to numbers of long-term experiments involved in the analysis; † Data derived from mixed models are shown as average ($\pm$ std deviation); Different letter within each land use type indicates significant difference among treatments at the 5% level. TNMR is defined as the percentage change in SOM content in external nutrient input treatments relative to initial values and control plots.

Table 5 Added yield benefits of combined organics and fertilizers on crop yields of selected long-term experiments in China.

Crop	Datasets*	Added yield benefits
		(kg ha ⁻¹) †
Wheat	139	-551.9 (±58.8) #
Maize	29	-2623.5 (±425.4)
Rice	121	-844.3 (±87.3)
All crops	295	-882.2 (±71.6)

* Refers to the total numbers of datasets involved in the analysis of selected long-term experiments; #Data are shown as average ($\pm$ std deviation); †Added yield benefits were assessed based on annual datasets by checking the interactive effects of organics+fertilizers on crop yields..

Figure legends

Figure 1. Trends of mean time by nutrient management response (TNMR) in yield over the duration of long-term experiments on various nutrient management strategies for wheat, maize and rice. TNMR is defined as the percentage change in yield in external nutrient input treatments relative to initial values and control plots.

Fig. 1