Understanding variability in maize yield response to phosphorus fertilizer in Africa and China: Meta-analysis

Kebeto Bilisuma (bilisak@yahoo.com)
National Academy of Agriculture Green Development, Ministry of Education, China Agricultural University

Xiaoqiang Jiao
National Academy of Agriculture Green Development, Ministry of Education, China Agricultural University

Lule Dagnachew
Oromia Agricultural Research Institute (IQQO)

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Abstract

The limited information on the relationship between phosphorus (P) fertilization and Agronomic efficiency of P (AEP) is a setback to farmers and agronomists for appropriate application of P fertilizer both in China and Africa. Besides, the gap between China and Africa on maize yield response to P fertilizer under different soil and rainfall condition is unknown. Therefore, this study aimed to quantify the variability of maize yield response and AE of P under various conditions using meta-analysis. It was shown that, both in Africa and China, the yield response was found to be 69.9%, and 20% higher compared to the control, respectively. Despite the fact that the magnitude of yield response depends on soil fertility, the level of NK (Nitrogen and Potassium) fertilizer applied, the genotype of maize, and agronomic practices, and types of P fertilizer used, a 49.99% higher yield response was obtained due to P fertilizer in Africa compared to China and the average AE of P was significantly higher in Africa (88 kg P kg^{-1}) than in China (33 kg P kg^{-1}). Under various soil and climatic conditions maize yield response was highly affected in Africa than in China. Therefore, in Africa wholistic approach of nutrient management and soil fertility improvement along with environmental safety issue should be developed, while in China, priority should be given to enhancing AEP of aimed at reduction of environmental pollution.

Introduction

Maize (Zea mays L.) is one of the most important food crops worldwide. It plays an important role in ensuring food security and raw material for industries in both China and Africa [1]. It is considered to have a high fertility requirement [2]. Ensues, application of P fertilizer is fundamental to increase maize productivity [3]. However, excessive P fertilizer is often applied to achieve high grain yield in China, and these high P fertilizer applications often mislead producers to believe that simply increasing inputs will produce more grain yield [4]. In China, the total P input to maize farm land in the 2000s was 1527 Gg (10^9 g) [5] and a small portion of this applied P was utilized by the crop in a single growing season, and the rest was accumulated in the soil as residual P [6]. In contrast, the African green revolution requires greater use of P fertilizers; compared to China, low P fertilizer use is common in Africa. Often-made comparisons note that fertilizer use rates in Africa were just 10–20% of those in Asia, Europe, and America [7], [8]. Additionally, the current level of agronomic nutrients used in farm trials in most Sub-Saharan African (SSA) countries is less than the required nutrient level to achieve the sustainable intensification of maize production in the region [9]. To achieve sustainable production, at least the nutrients removed through exportation of agricultural products must be returned to the soil, but the nutrient imbalance in agricultural production is currently one of the main threats to the soil in SSA [10], [11].

The yield response of maize to P fertilizer is defined as the percentage increment of maize yield between NPK (Nitrogen, Phosphorus and Potassium) and CK (without application of P fertilizer) and AE is the amount of maize yield increase per unit of P fertilizer applied [12]. Different factors contributed to the difference in maize yield response to P fertilizer. Some of the factors that affected maize yield were: management practice, environmental factors like water availability and soil and climatic conditions were the primary contributors. For achieving high yield response and high P use efficiency (PUE), management of hybrid varieties, improvement in soil fertility, and improvement in P application are essential [13]. Besides, Higher maize yield response and AE does not correspond with high P fertilizer application [14]. As the level of P fertilizer application increased, P adsorption from the soil increased gradually, but there was a progressive decrease in the percentage of added P absorption [15]. The average critical values of soil Olsen P for maize production in China was ranged from 12.1 to 17.3 mg kg^{-1} with the average values of 15.3 mg kg ha^{-1} [16], so the addition of chemical fertilizer on soil which has soil Olsen P higher than 15.3 mg kg^{-1} increase a little to maize yield or the yield response of maize to chemical fertilizer above this point is minimal.

Understanding the correlation between the maize grain yield and P uptake is very important to reduce the cost and environmental impact of maize production [17]. The limited information on the relationship between P fertilizer and maize yield response affected the national P management policies and become a setback to agronomists and farmers to put the necessary nutrient required to the crop and become the reason for excess application of P fertilizer to the crop in the pursuit of high yield in China [18] and still, the wholistic approach is needed to substantially improve the nutrient yield response and AE of both on-farm trials and millions of farmers' fields in China [19], [20].

Low P fertilizer application in Africa and high P fertilizer application in China are contrasting trends. This creates the difference in agronomic response of maize yield to P fertilizer application and nutrient use efficiency (NUE) in China and Africa. So optimizing the P fertilizer application rate can increase maize grain yield while reducing both cost and environmental impact [14]. Meta-analysis has been used to generate information from diverse studies performed under various conditions which is difficult to summarize using a single study. The response ratio (the ratio of the mean outcome in the experimental group to that in the control group) is often used as a measure of the effect of magnitude in meta-analyses [21]. Therefore, to understand these contrasting scenarios under various conditions meta-analysis is more important than individual review methods. As a result, this meta-analysis was designed to quantify the response of maize yield to P fertilizer under various soil and climatic conditions in Africa and China.

Materials And Methods

Database compilation

Our database was populated with 1673 individual observations across 149 peer-reviewed papers from thirteen (13) African countries and China. The details of information about papers considered in this meta-analysis are provided in the supplementary information. The geographic distribution of each paper was presented in figure S1. These papers were retrieved from online search engines, such as Google Scholar, Taylors, and Frans, Web of Science and China National Knowledge Infrastructure (CNKI), with the keywords "P" OR "phosphate fertilizer" AND "yield" AND "maize" AND "Africa" OR "China" or replacing specific African country names in place of Africa to be more specific for our search. To minimize bias, the literature search was restricted to peer-reviewed journal articles of field experiments with three replications, as a result, pot and greenhouse experiments were not included. Maize yields were obtained directly from tables and/or text of the papers or extracted from the figures using the get data graph digitizer V2.22 software (http://getdata-graph-digitizer.com/).

Response Variable

The response variable used was maize grain yield kg ha^{-1}, and each observation was considered in the database.

Explanatory Variables

Additional factors were taken from the studies and included in the database because of their important influence on maize yield. These moderator variables include the soil and climatic conditions, such as the mean annual precipitation (MAP), soil available P (AP), soil organic matter (SOM) (Table 1).

Data analysis

In this study response ratio (RR) was used as effect size. It was calculated as the natural log of the relative change in maize yield between treatment group and control group using the following formula.

$$lnRR = ln\left(\frac{T_{NPK}}{T_{NK}}\right) \quad (1)$$

Where *lnRR* is the natural log of the response ratio (the effect size), T_{NPK} is maize yield under P fertilizer, and T_{NK} *is* maize yield without P fertilizer [21]. Most of studies in our data base did not reported the variance of their observations which put setback to perform weight of individual studies, to overcome this setback, number of replications of the experiment were used to calculate weight of each observation using WI=(Rt*Rc)/ Rt+Rc, where WI is weight of individual observation, Rt and Rc were number of replication of data in treatment and control respectively based on Adams et al.[22]. The 95% CI (Confidence interval) was generated using bootstrapping (4999) iterations with a biased-corrected confidence interval in Metawin version 2.1 based on Hedges et al.[21] The RR was transformed to percentage using (lnRR-1) x 100 and for easy interpretation, it was presented in the text and graphs as percentage change in yield due to P fertilizer compared to control [23]. The generated lnRR distribution of maize under treatment group and control was not a distinctive normal distribution ($P < 0.05$) (Figure S2a and S2b). Therefore, to compare the significance difference between maize yield response to treatment (T_{NPK}) and control (T_{NK}) group between China and Africa, and to test the extent of variation among the moderator variable listed in table 1, we used one one-way ANOVA at ($P < 0.05$). For easy explanation of the percentage changes in maize yield, box plots and horizontal errors bars were used. Averages of the percentage change in yield due to P fertilizer between China and Africa, as well as the average percentage change in yield due to P fertilizer between different moderator variables were considered to be significant at ($P < 0.05$) when 95% CIs did not overlay with each other and they were considered to be significantly different from control when 95% CIs did not overlay with zero [21].

Publication bias

The systematic errors that arise when research articles are not published due to minor findings, tiny effect sizes, or undesirable outcomes are known as publication bias. It alters our perceptions of scientific evidence and can lead to over- or under-estimation of the pooled estimate for the measure of effect between exposure and outcome. The funnel plot is a simple approach to display the study's effect size in relation to its precisions. When a meta-analysis is free of publication bias, the funnel plot is wide at the bottom and narrows as it gets closer to the top. A funnel plot was used in this study to demonstrate publication bias using a random effect model. Both in Africa and China, the funnel plot showed incredibility significant effect ($p < 0.001$) indicating no publication bias (Figure S3).

Agronomic efficiency of P (AEP)

P agronomic efficiency (AEP) in this study was used to estimate chemical P fertilizer efficiency. It was calculated as:

$$\mathrm{AEP}=\frac{T_{\mathrm{NPK}}-\mathrm{T}_{\mathrm{NK}}}{F_P} \qquad (2)$$

T_{NPK} is maize yield under P fertilizer, and T_{NK} *is* maize yield without P fertilizer and FP is the amount of fertilizer applied kg P ha^{-1}.

Data management

In this study meta-analysis was performed using Metawin version 2.1 based on Hedges et al. [22]. For visualization of experimental location both in Africa and China, ArcGIS version 10 (Environmental system research institute, Inc. USA) was used. Mean separation for some data was performed using SPSS 22.0 version (SPSS Inc., Chicago, IL, USA) and graphing was done by Sigmaplot version 10 software (Systat Software Inc., San Jose, CA, USA).

Result

Maize yield response to P fertilizer and agronomic efficiency in Africa and China

A positive maize yield response to P fertilizer was observed in both Africa and China (Figure 1). On average, 69.9% higher yield increase in Africa resulting from P fertilizer use was obtained across 1,213 cases, which was significantly higher ($P < 0.01$) than the yield increase in China (19.6%). In both China and Africa, P fertilizer greatly contributed to the increase in maize yield, and without P fertilizer maize yield reductions in Africa and China were 35.75% and 14.1%, respectively. Although the magnitude of the yield increase depends on soil fertility, the level of NK fertilizer applied, genetic, and agronomic practices, 49.99% higher yield increase due to P fertilizer application was obtained in Africa than in China. The maize yield with P fertilizer in China was 8.8 tons ha^{-1}, which was significantly higher than in Africa (3.9 tons ha^{-1}). Besides, maize yield without P fertilizer and soil AP was significantly higher in China than in Africa (Figure 2ab). Maize yield without P fertilizer was 2.4 tons ha^{-1} and 7.5 tons ha^{-1} in Africa and China respectively. Maize yield without P fertilizer and the content of soil AP was significantly higher in China than in Africa (Figure 2ab). Meanwhile, correlation of yield response to P fertilizer used was strong in Africa compared to that of maize yield response in China.

Maize yield response to chemical P fertilizer was varied among different P fertilizer type in Africa and China (Figure 3 and 4). In China, the highest yield response was found in order of MAP > DAP > SSP > TSP > FMP respectively and there was insignificant difference of yield response variation among SSP, TSP and DAP (Figure 4). While in Africa, the yield response of maize showed significant variation among different types of P fertilizer used. The highest yield response was found in the order of combination of rock phosphate and TSP > TSP > SSP > Rock phosphates > DAP (Figure 3). The correlation between P fertilizer used and yield response ratio was strong and positively correlated (R^2 0.045), the correlation was stronger and more positive in Africa than in China (R^2 0.0059 and 0.018) respectively.

The average AE of P fertilizer used in maize production was 88 kg P kg^{-1} in Africa, which was significantly higher than in China (33 kg P kg^{-1}) (Figure 5). In China, the AEP values were in the range between 191 kg P kg^{-1} to +488 kg P kg^{-1} and in Africa, it was in the range between -79 kg P kg^{-1} to +932 kg P kg^{-1}. The study revealed that there was higher maize yield and lower AE of P fertilizer in China than in Africa. There was more strong positive correlation of AEP and fertilizer used in than in China (Figure 5)

Factors influencing the response of maize yield to P fertilizer in Africa and China

The maize yield response to P fertilizer varied significantly among the different soil and climatic conditions in both Africa and China (Figures 6 and 7). Maize yields were significantly influenced by the change in MAP in Africa, but not in China. In Africa, maize yield was significantly higher when MAP > 800 mm than when MAP < 800 mm (Figure 6). In contrast, no significant difference in maize yield responses to P fertilizer was observed between MAP < 800 mm and MAP > 800 mm in China.

The response of maize yield to P fertilizer was also affected by soil conditions (Figures 4 and 5). In both Africa and China maize yield response to P fertilizer at soil pH > 7 was higher than at soil pH < 7 (Figures 6 and 7). However, the change in maize yield was significantly higher in Africa than in China under both conditions. Besides, there was a significantly higher change in maize yield in Africa at SOM < 15 g kg^{-1} than at SOM >15 g kg^{-1} with mean values of 72% and 50% respectively. In contrast, no significant difference in maize yield responses to P fertilizer was observed in China between SOM < 15 g kg^{-1} and SOM >15 g kg^{-1} (Figure 7). In relation to the initial soil AP, a significant maize yield increase was observed above critical soil AP (AP >15) and below critical soil AP (AP >15) in both Africa and China (Figures 6 and 7). However, the magnitude of change in maize yield due to P fertilizer under different soil AP was significantly higher in Africa than in China.

Discussion

This study demonstrated that yield increase resulting from the use of phosphate fertilizer in maize production was considerably important. Similarly, Withers et al. [24] reported that, the use of Phosphate fertilizer to meet food demand of human population and animal feed is significantly important and due to the use of Phosphate fertilizer in agricultural production, the level of production on world was boosted and enhanced [25]. As an example, during the past three or four decades, on average, 7–33% yield increased was obtained in grain production in China [26],[13]. The present study also concords their finding that, on average maize yield was increased by more than half due to P fertilizer application. Further, this study showed that maize yield response to P fertilizer was significantly varied between China and Africa, high yield response in Africa and low yield response in China was due to the enormous difference in P fertilizer application. Our result concords prior researched primary maize growing regions under different soil and climatic conditions in China [18]. This implies that, although a lot of factors contribute to the variability of yield response, P fertilizer is an important source of yield increment. However, high P fertilizer application does not correspond with high yield. The study conducted on three levels of P application rate (Low, Medium, and High) revealed that the mean yield response of maize under high treatment was 12.69% higher compared to the control, but 4.3% lower compared to the medium treatment [14]. This is a good manifestation that, the high yield response of maize in Africa compared to China was due to the low level of P fertilizer application and P fertilizer application in China were in excess quantity and the yield response of maize was not directly proportional to high P fertilizer application.

Maize yield without P fertilizer in China was significantly higher compared to African maize yield without P fertilizer. This huge difference was attributed to the good soil condition in China than in Africa. In China, the national average yield of maize without P fertilizer was 7774.6 kg ha^{-1} and it was consistent with our finding [18], [13]. The study conducted on large experimental size (419 on farm experiment) in Northwestern China revealed that soil residual P was an important source of nutrient for maize due to accumulation of P in the soil of China, ensues the average yield of maize without P fertilizer was high. Contrary to this, maize yield without P fertilizer was low due to the low application of P fertilizer in Africa. In Western Kenya omitting P fertilizer would reduce the yield of maize by 50% [27]. In SSA, even though sustainable intensification of agriculture is in balancing act between increasing nutrient inputs while ducking unnecessary nutrient loss to the environment, the current level of agronomic nutrient use in Africa is too low [28]. The huge variation between maize yield without P fertilizer in Africa was attributed to the difference in soil condition, the level of NK fertilizer used, agronomic practice, and environmental conditions like water availability.

Yield response to P fertilizer was varied based types of P fertilizer used. Looking at the overall result, highest maize yield response was achieved when combination of TSP and rock phosphate was used followed by TSP alone, rock phosphate, MAP, SSP, DAP, and FMP. Specifically, in Africa and China, yield response was higher when combination of rock phosphate and TSP and MAP was used. This variation of maize yield response to different types of P fertilizer was due to the nature of P mobility in soil and soil characteristics [29]. And different types of P fertilizer has different characteristics that may affect the availability of P to the crop under cultivation [30], [31]. For example, the P movement capacity of SSP is lower than that of DAP and MAP [32]. More importantly, Ca and Mg in alkaline soil affects the availability of P to crop root, while in Acidic soil, Fe and Al affect the accessibility of P by the crop root [30], [33]. This has provided the evidence that yield response to phosphate fertilizer was strongly associated with P fertilizer characteristics and soil P fertility. Ensues, it is very important to improve PUE by integration of P fertilizer types, soil and crop characteristics [34].

AE of P fertilizer used in Africa was significantly higher compared to China. This was attributed to the low level of P fertilizer application in Africa. Contrary to this, excess application of P fertilizer significantly reduced the AE of P fertilizer used in China. At a high level of P fertilizer application, the yield response and AE of P fertilizer decreased [18]. Additionally, the average AEP in low treatment and high treatment were highly declined by 23% and 55.7% compared to medium treatment. The medium application rate had a higher AEP because of the low application rate and higher grain yield obtained [14]. The highest AEP was achieved when the application rate of P fertilizer was low [27]. In excess P fertilizer use and P surplus areas of the world, additions of P fertilizer to the farm slightly increase the productivity of the crop under cultivation [35]. Generally, due to differences in soil, environmental factors, and management practices, yield responses, and AE of P can differ widely across different regions of the world [19], [3637].

Soil and climatic factors significantly influenced maize yield response to P fertilizer. This is consistent with the prior published research of Yan et al.[18] which reported that the critical point of soil AP is the value at which the addition of further chemical P fertilizer would increase nil or a little to the crop yield. At soil AP below a critical level (15 mg kg^{-1}), the yield response and AEP increased with increasing soil AP, however, above the critical level of soil AP, the yield response and AEP remain constant. The AE and yield response of maize can vary depending on the soil fertility and environmental conditions [36], [37],[19]. Zhang et al. [37] also reported that, at a low level of soil AP, there is a high yield response of maize to applied P fertilizer, and as the level of soil AP increases, the yield response to P fertilizer starts to decrease until it reaches the leaching point of P from the soil [38]. Different maize cultivation regions in China had different AE of P fertilizer used [18]. This study further strengthens their finding that the significant variability between China and Africa on the influence of soil AP on maize yield response and AE aroused from the high AP in the soil of China and low soil AP in Africa.

The response of maize yield to P fertilizer when SOM < 15 g kg^{-1} was higher than when SOM > 15 g kg^{-1} and the yield response ratio started to decrease as the level of SOM increased. This result is consistent with the finding of Lu et al. [39] that reported maize yield response to crop residue management was higher when SOM was < 15 g kg^{-1} SOM than when SOM > 15 g kg^{-1}. Besides, SOM was an important yield influencing soil factors, accounting for a greater percentage change in crop yield, and showed a decreasing effect as the level of organic matter increased in the soil [40].

The maize yield responses to P fertilizer under different pH was similar in both China and Africa. At pH > 7, maize yield response was higher than at pH < 7. This concord the finding of Yan et al., 2021 which reported the yield response and AE in alkaline soil (pH > 7) were significantly greater than those in acidic soil (pH < 5.5) and neutral (pH in 5.5–7.0) soils. Additionally, there was a significant difference between the mean AE of P in alkaline soil (12.82 kg kg^{-1}) and those in acidic (11.02 kg kg^{-1}) and neutral (11.37 kg kg^{-1}) soils, but no significant difference between neutral and acidic soil. [41] also reported that in acidic soil, the P absorption of maize was lower than that in neutral soil, resulting in lower yield and PUE. One of the most important role of pH is playing huge role in transformation heavy metal [42,43], and also in high pH soil, it has an significant role on the degree of P fixation by calcium (Ca), aluminum (Al), and iron (Fe) minerals and at the end it affects the solubility of P in soil [44].

Under optimum rainfall conditions, the maize yield response to P fertilizer was higher in Africa than in China. The difference in yield response under different rainfall conditions was attributed to the use of irrigation in China, while in Africa maize production depends on erratic rainfall. Ensues small difference in rainfall distribution in Africa would have an effect on maize production, while in China irrigation facilities avoided the drought effect on maize yield and no difference was seen under different rainfall conditions in China. Lu, [39] reported that at MAP ≥ 800 mm $year^{-1}$, the yield increase due to the crop residue management was high. Although it depends on the amount of P fertilizer, low rainfall distribution affect maize yield [45]. This is because, under optimum soil nutrient and low rainfall conditions, the yield of maize could be low, and low daily rainfall events do not allow enough crop growth for survival.

Conclusion

The variability of maize yield response and agronomic efficiency of Phosphorus fertilizer between China and Africa were summarized using meta-analysis under different soil and climatic condition. It was shown that the yield response of maize to Phosphorus fertilizer and its agronomic efficiency were significantly higher in Africa than in China. Both yield response and Agronomic efficiency were 50% higher compared to China. Besides, soil and climatic conditions influenced maize yield response and agronomic efficiency in both Africa and China. However, their influence is higher in Africa than in China. This means that the soil condition in China is a stable and important source of nutrients than in Africa. Further, Agronomic practice and management are also the major factor contributing the huge variation of yield response between China and Africa. Therefore, for sustainable maize production, in China, improvements in Phosphorus use efficiency with more integrated management of fertilizer and improvement of farmers agronomic practices will be helpful to minimize the regional Phosphorus surpluses, while in Africa, the holistic approach of nutrient management, soil quality improvement, and improvement in farmer agronomic practices are advised for sustainable maize production and food security.

Declarations

Conflict of interest

The authors declare that they do not have any competing **interests.**

Authors contributions

Bilisuma K collected data, analyzed and drafted manuscript, Jiao X, Supervised, revised and edited manuscript, Dagnachew L Revised and edited manuscript.

Data availability statement

The original contributions presented in the study are included in the article, and further inquiries can be directed to the corresponding author.

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Tables

Table 1. Moderator variables used in Meta -analysis

Moderator variables	Groups
Soil pH	pH < 7 and > 7
Soil organic matter (g kg^{-1})	SOM < 15 g kg^{-1} and > 15 g kg^{-1}
Soil available P (mg kg^{-1})	SAP < 15 mg kg^{-1} and >15 mg kg^{-1}
Mean annual precipitation (mm $year^{-1}$)	MAP < 800 mm and MAP > 800 mm

The moderator variables were classified based on the average values of the database. pH was assumed to be acidic at < 7 and alkaline at > 7. Soil AP was classified based on (Yan et al., 2021, Tang et al., 2009) critical values for maize in China.

Figures

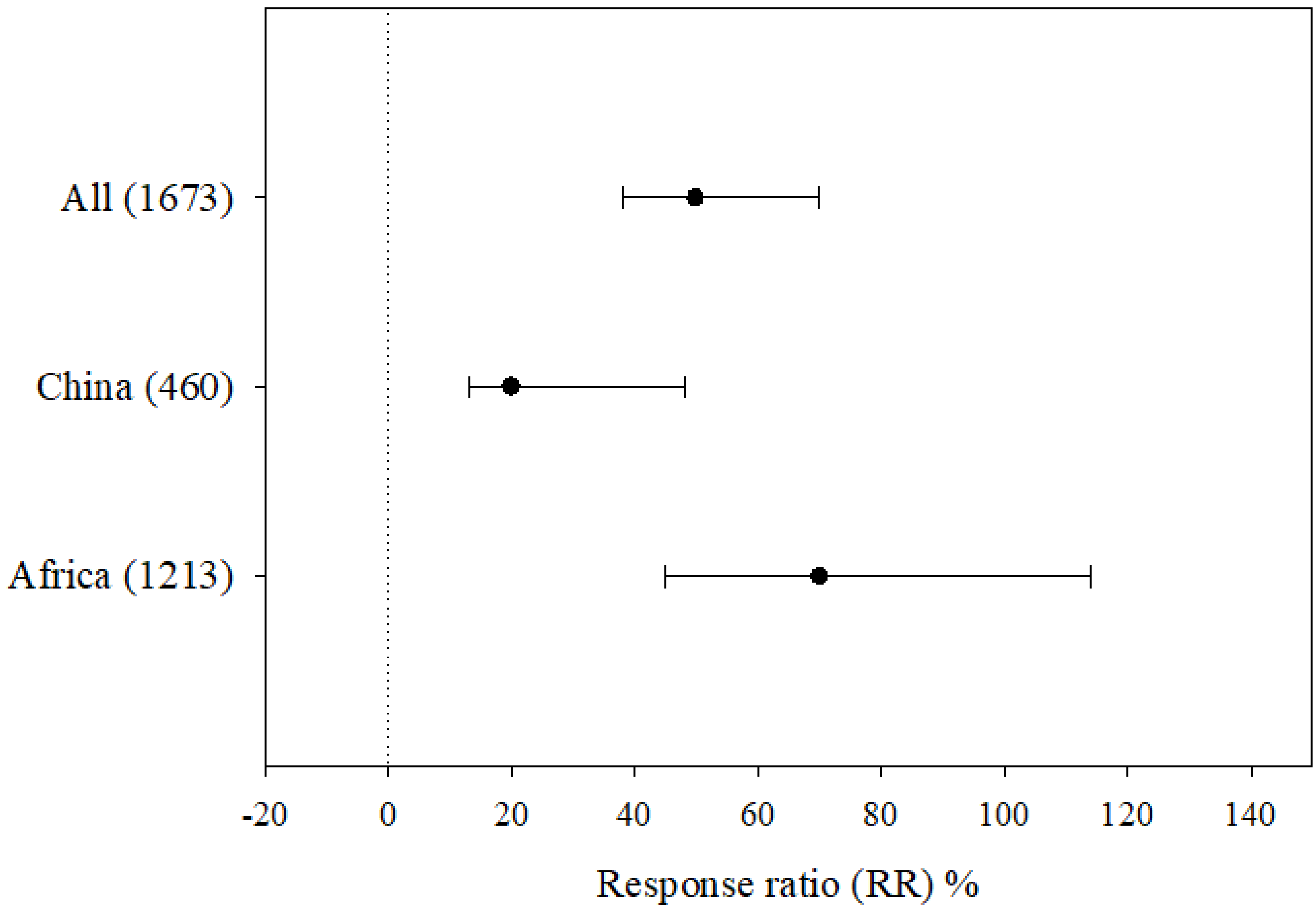

Figure 1

Change in yield (%) of maize in Africa and China. A number of observations are given in parenthesis, the error bars represent 95% confidence intervals (CIs). The yield increase was significantly different between China and Africa when the 95% CIs did not overlap with each other, When 95% CIs did not overlap with zero it was significantly different from control

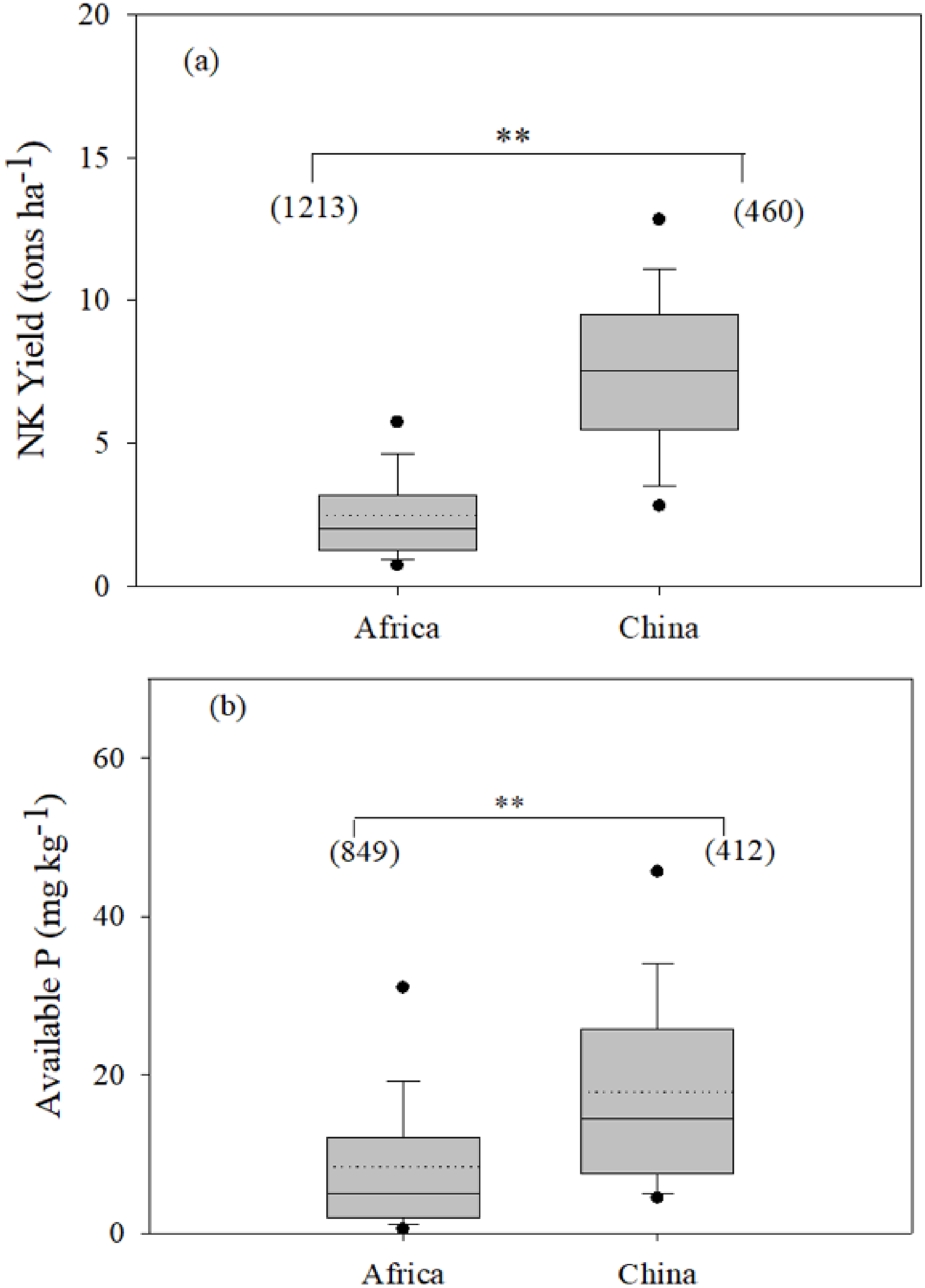

Figure 2

Soil available phosphorus (a) and maize yield without P fertilizer (NK) (b) in Africa and China. Black solid and dotted lines indicate medians and means, respectively. Box boundaries indicate upper and lower quartiles, whisker caps indicate 95th and fifth percentiles, and circles indicate outliers. The number of data points is given below each box. ** denotes significant different at $P \leq 0.01$.

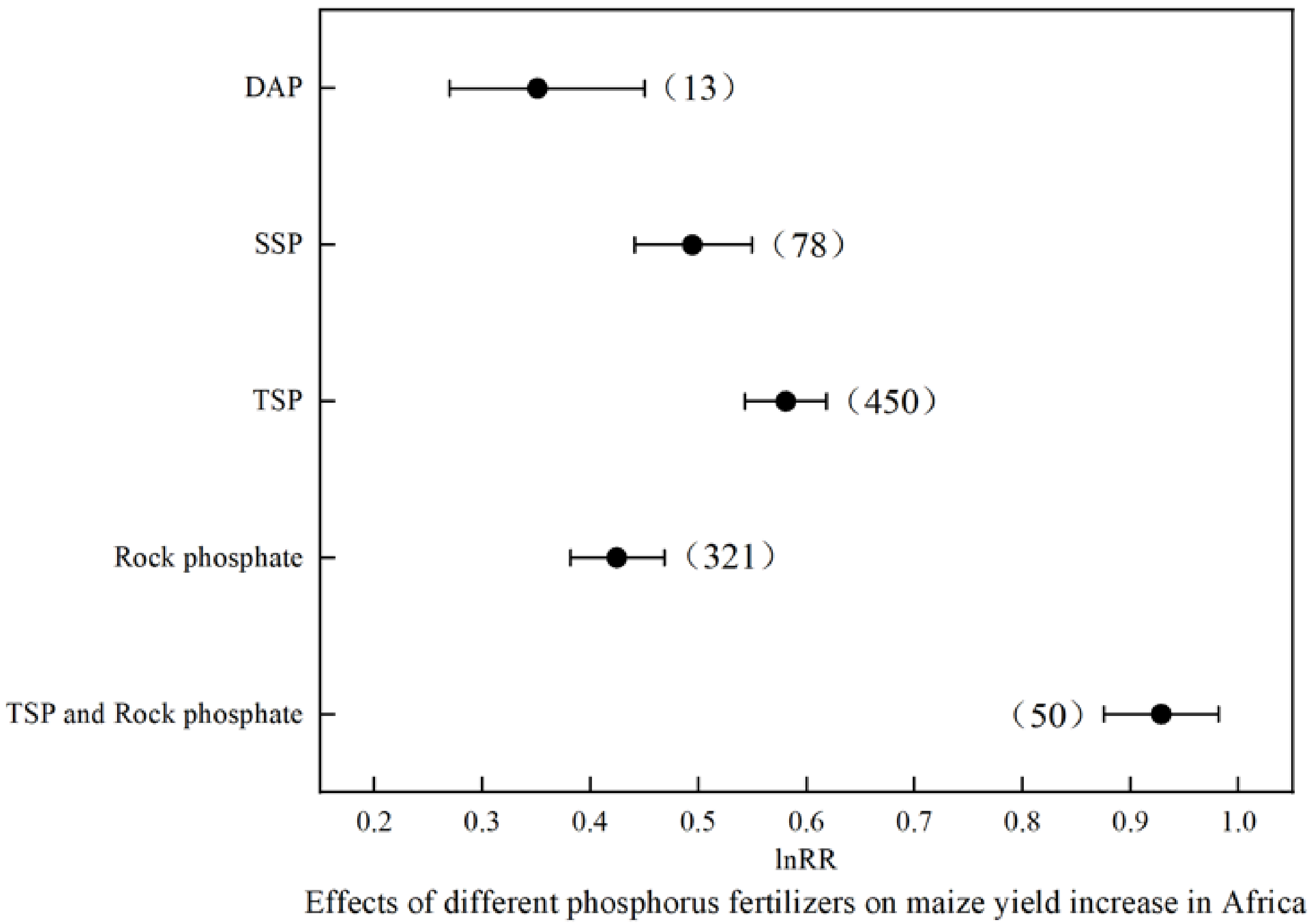

Figure 3

The influence of different types of P fertilizer on effect size in Africa. Number of observations are given in parenthesis, the error bars represent 95% confidence intervals (CIs). The yield increase was significantly different among different soil conditions and rainfall when the 95% CIs did not overlap with each other, when 95% CIs did not overlap with zero, it was significantly different from control. DAP-Diammonium phosphate, SSP- Single Super phosphate, TSP-Triple super phosphate.

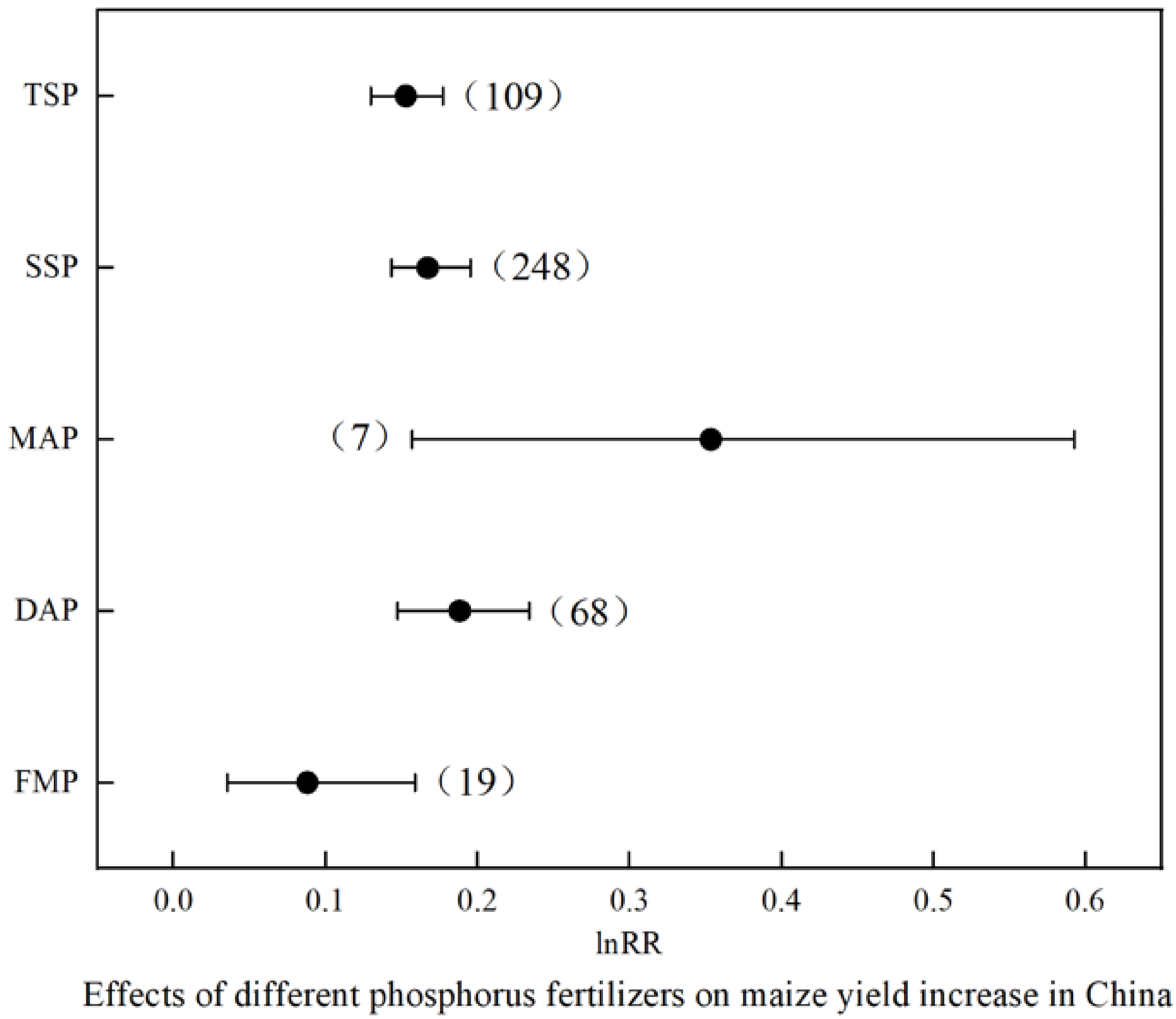

Figure 4

The influence of different types of P fertilizer on effect size in China. Number of observations are given in parenthesis, the error bars represent 95% confidence intervals (CIs). The yield increase was significantly different among different soil conditions and rainfall when the 95% CIs did not overlap with each other, when 95% CIs did not overlap with zero, it was significantly different from control. DAP-Diammonium phosphate, SSP- Single Super phosphate, TSP-Triple Super Phosphate, MAP- Mono ammonium phosphate, FMP- Farm yard manure phosphate.

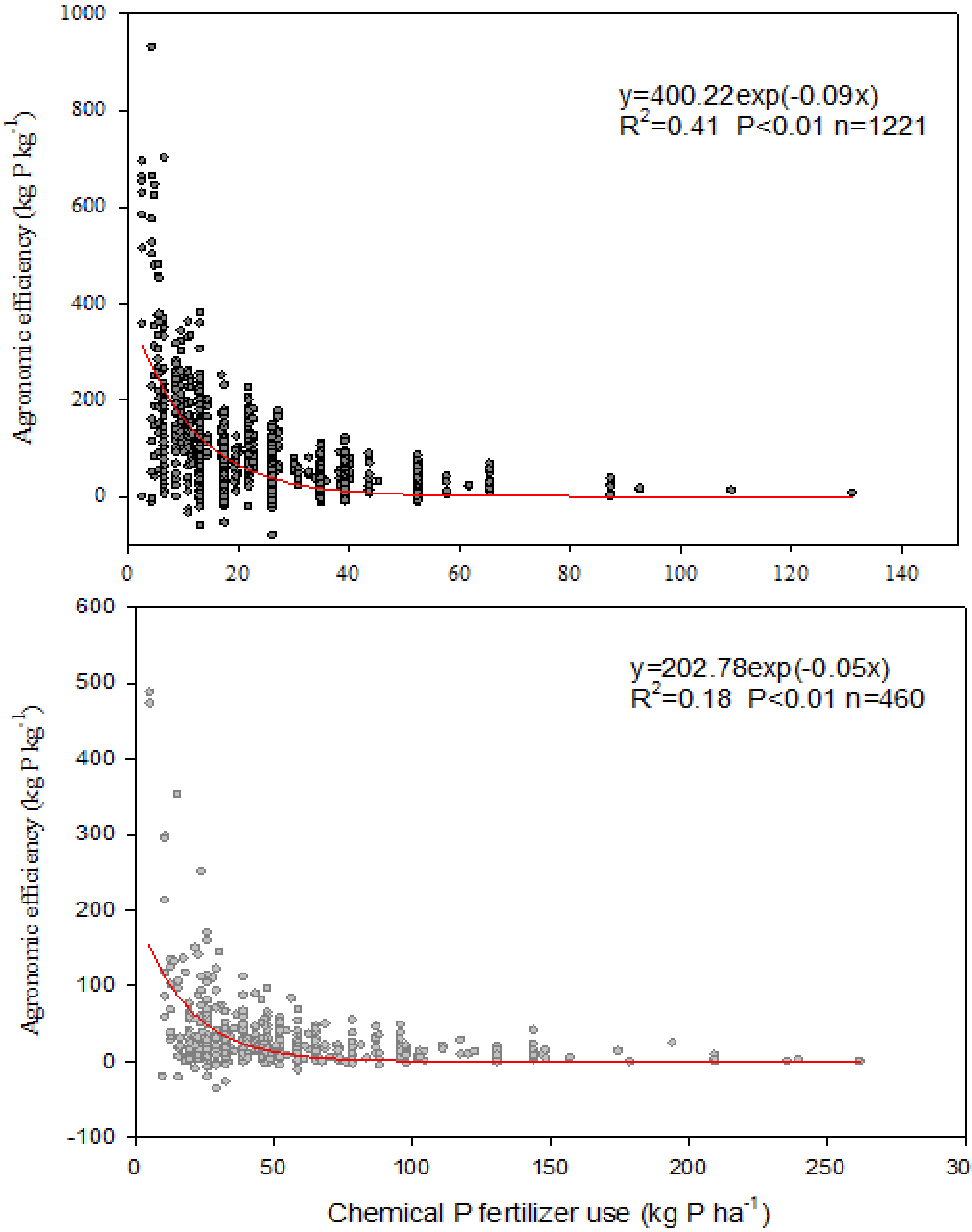

Figure 5

The relationship between Agronomic efficiency and P fertilizer used (kg ha^{-1}) in Africa (a) and China (b).

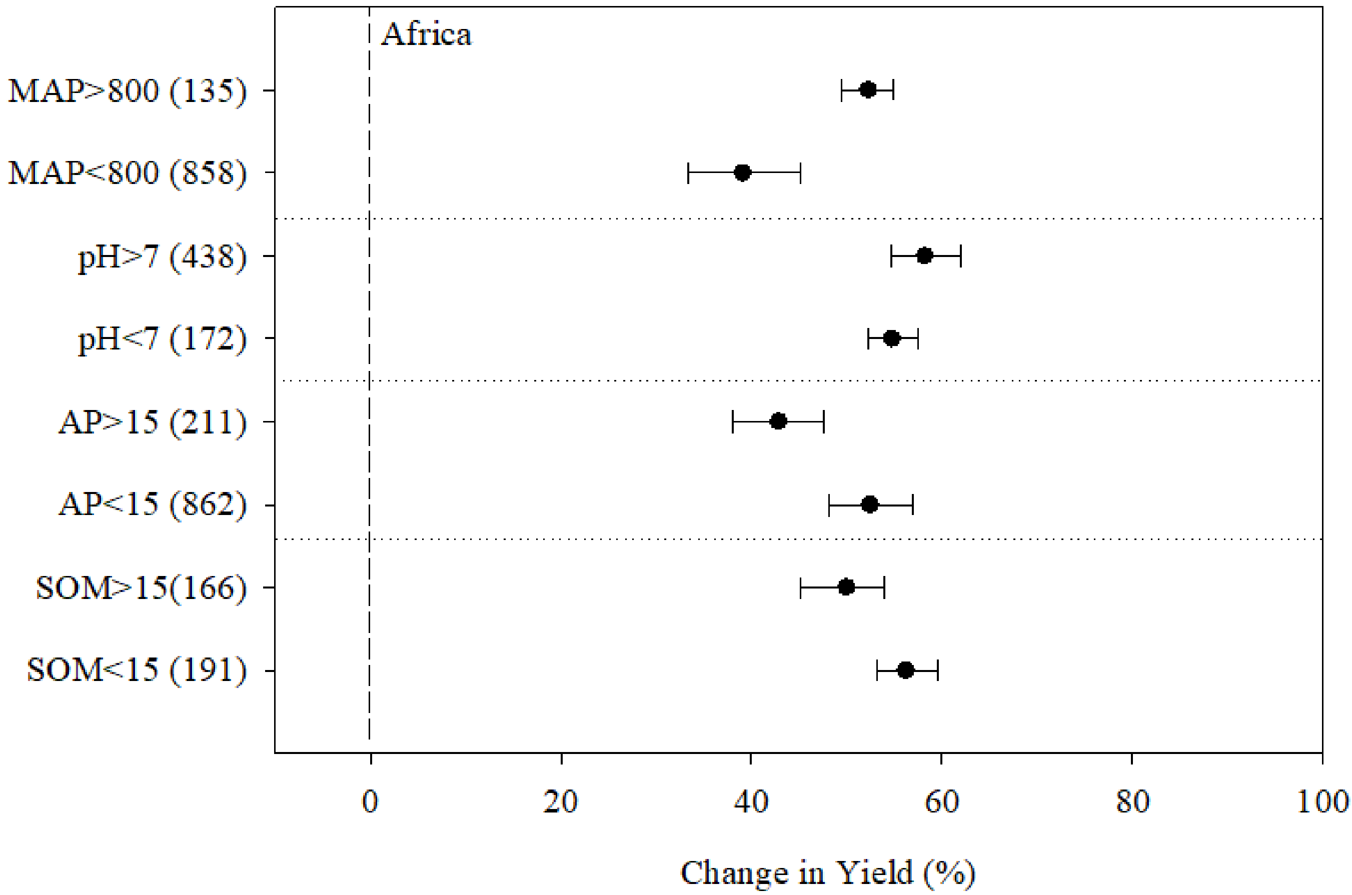

Figure 6

The influence of soil and climatic factors on maize yield due to P fertilizer in Africa. Number of observations are given in parenthesis, the error bars represent 95% confidence intervals (CIs). The yield increase was significantly different among different soil conditions and rainfall when the 95% CIs did not overlap with each other, when 95% CIs did not overlap with zero, it was significantly different from control. SOM, Soil Organic Matter, AP, Available Phosphorus, MAP, Mean Annual Precipitation.

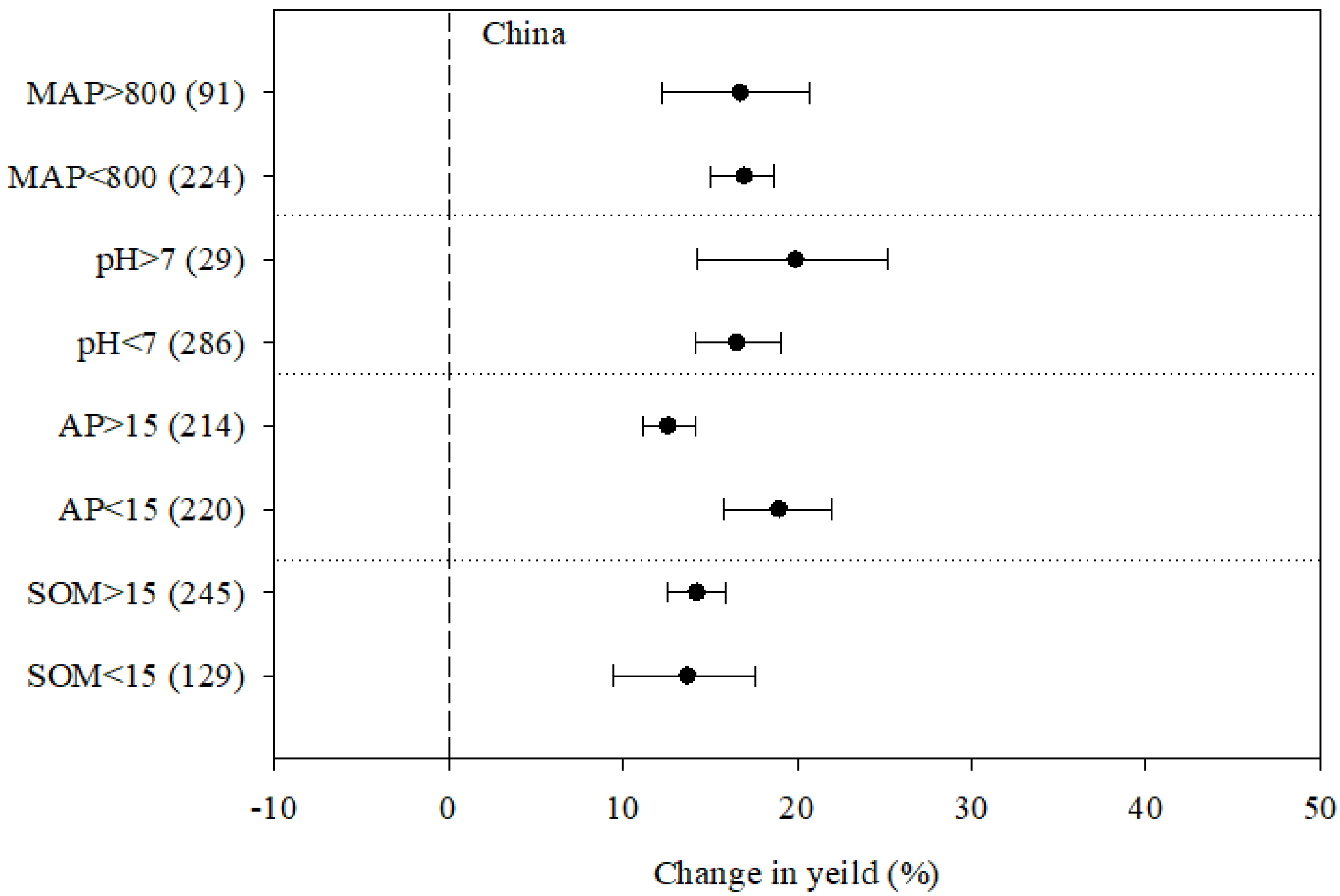

Figure 7

The influence of soil and climatic factors on maize yield due to P fertilizer in China. Number of observations are given in parenthesis, the error bars represent 95% confidence intervals (CIs). The yield increase was significantly different among different soil conditions and rainfall when the 95% CIs did not overlap with each other, when 95% CIs did not overlap with zero, it was significantly different from control. SOM, Soil Organic Matter, AP, Available Phosphorus, MAP, Mean Annual Precipitation.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix1.xlsx
- SupplementaryDatasetFile.xlsx
- Supplementaryfigure.docx