Agricultural Sciences, 2022, 13, 612-631
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

# Grain Yield and Nitrogen Use Efficiency Vary with Cereal Crop Type and Nitrogen Fertilizer Rate in Ethiopia: A Meta-Analysis

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**How to cite this paper:** Yokamo, S., Jiao, X.Q., Jasper, K., Gurmu, F., Jahan, M.S. and Jiang, R.F. (2022) Grain Yield and Nitrogen Use Efficiency Vary with Cereal Crop Type and Nitrogen Fertilizer Rate in Ethiopia: A Meta-Analysis. *Agricultural Sciences*, **13**, 612-631.
https://doi.org/10.4236/as.2022.134041

**Received:** March 13, 2022
**Accepted:** April 26, 2022
**Published:** April 29, 2022



## Abstract

The crop production in Ethiopia is markedly constrained by soil nutrient depletion and limited fertilizer input. Nitrogen is among the most yield-limiting factors of cereal crops, especially in sub-Saharan Africa (SSA). A meta-analysis of 82 studies was carried out to evaluate the response of major cereal crops, viz. wheat, maize, barley, teff, and sorghum, to nitrogen fertilization in Ethiopia. The results showed that N-application significantly increased yields of all the five crops examined herein. The average yields of the treatment effects over controls for the five crops were 3775.8 kg·ha$^{-1}$ and 2593.3 kg·ha$^{-1}$, respectively. The overall yield response to nitrogen treatments for all the crops was 64.8% (wheat, 96.5%; maize, 40.65%; barley 84.36%; teff, 50.48%; and sorghum; 23%). Overall, nitrogen agronomic efficiency ($AE_N$) and partial factor productivity ($PFP_N$) were 18.2 and 71.81 kg·kg$^{-1}$, respectively. A downtrend of nitrogen use efficiency with an increase in N rate was realized. The yield response was higher for the nitrogen treatment effects of >100 kg·N·ha$^{-1}$ (123.9%), clay soils (75.46%), low initial soil organic carbon (SOC) and available phosphorous (AP) (92.4% and 101.6%), respectively, Therefore, we recommend the application of nitrogen fertilizer (>100 kg·N·ha$^{-1}$), especially on infertile soils for improved grain yield and NUE in aforementioned cereal crops in Ethiopia and similar regions in sub-Saharan Africa (SSA).

**Keywords**

Cereal Crop, Nitrogen Rate, Nitrogen Use Efficiency, Meta-Analysis, Yield

## 1. Introduction

Food insecurity is one of the major concerns, particularly in sub-Saharan Africa (SSA) given the escalating population, climate change and persistently stagnated crop yields [1]. Feeding the growing world population by meeting the high demand for food is one of the major challenges [2] [3] [4]. Ethiopia is the second most populous country in Africa and food insecurity is an enduring and critical issue. Among food crops in high demand are the cereal crops of which teff (*Eragrostis tef*), maize, wheat, barley, and sorghum are the most vital cereal crops in terms of plantation area and the volume of production. These crops are grown by about 16 million smallholder farmers [5] and have high economic importance with regard to household food security [6] [7]. According to the report of Central Statistical Agency (CSA) [8], among 12.73 million hectares of total land area covered by grain crops in the country, approximately 10.4 million hectares (>81%) are covered by cereal crops.

Although the government of Ethiopia allocates about 10% of its total expenditure to the agricultural sector (which is the benchmark of New Partnership for Africa's Development (*NEPAD*) for sub-Saharan Africa); the productivity of cereal crops is below the global average due to several biotic and abiotic factors [5] [6]. The Ethiopian average cereal yield is low (2.45 $t \cdot ha^{-1}$) [5] as compared to the world average of 3.9 $t \cdot ha^{-1}$ [9]. The report of CSA of Ethiopia revealed that the mean yield for major cereal crops is about 3.8 $t \cdot ha^{-1}$ (maize), 1.7 $t \cdot ha^{-1}$ (teff), 2.1 $t \cdot ha^{-1}$ (barley), 2.7 $t \cdot ha^{-1}$ (wheat), and 2.5 $t \cdot ha^{-1}$ (sorghum) [10]. The low productivity is mainly attributed to soil fertility depletion. The extensive variability in soil fertility status, climate and nutrient management among farmers further contribute to poor crop production and productivity in Ethiopia [11]. Acute crop cultivation, poor straw management and its complete removal from the field are also major challenges affecting food production. In order to improve soil quality and boost food production, the nutrient status of the soil has to be maintained by applying chemical and/or organic fertilizers [12]. The use of organic fertilizer in farmland is the most important practice of soil improvement and thereby crop production. It is crucial to augment the low nutrient supply status, particularly in low-input and low-output regions such as Ethiopia. Yengoh [13] reported that the use of animal droppings and compost improves the soil structure, enhances soil aeration, and increases grain yields. However, this and other important agricultural technologies are not widely promoted in the country due to several socio-economic and institutional factors [14] and also its use for other competing needs *i.e.*, such as animal feed, fuel for cooking, and fencing [15]. Urea and di-ammonium phosphate (DAP) fertilizer are the only sources in Ethiopia that are used for about four decades in blanket form and balanced fertilizers containing both macro and micronutrients in blend form have been recommended recently [16].

The use of chemical fertilizer in arable land in SSA and specifically in Ethiopia is far below the global average. The average fertilizer use in Ethiopia remains 16 kg·ha$^{-1}$ and it is about 34 kg·ha$^{-1}$ in maize production [17]; this amount is below the "Abuja's Declaration on Fertilizer for the African Green Revolution" of 2006 in which the African Union adopted to raise fertilizer consumption to 50 kg·ha$^{-1}$ by 2015. The reason for the inadequate use of chemical fertilizer is due to high price (expensiveness), inaccessibility and unavailability at the relevant time and place, limited access to credit and input services, weak extension systems, weak infrastructural development, institutional and demand-side problems, and information gaps [18] [19]. However, continuous farming on marginal soils without supplying adequate soil nutrients deteriorates soil quality [20] and thereby stagnates crop yield.

Nitrogen fertilizer is the most limiting factor of the growth and development of crops and it is an essential macronutrient required in large amounts [21] [22]. It profoundly impacts soil health by influencing SOM, pH, and other soil properties. Nevertheless, nitrogen management practices [23], genotypes [24], and environment [11] [25] have a significant influence on nitrogen use efficiency (NUE). Nitrogen use efficiency is a measure of the amount of nitrogen absorbed by the plants and the amounts lost from agricultural fields to the environment [23], thus the efficiency of nitrogen use. Globally, NUE in cereal crop production is estimated to be low (~33%) [26]. Average across three different sites in Ethiopia, the NUE (expressed in agronomic use efficiency ($AE_N$)) for maize crops ranged from 4.25 kg·kg$^{-1}$ (in Bulbula) to 29.6 kg·kg$^{-1}$ (in Jimma) [11], while it ranged from 2.22 to 10.48 kg·kg$^{-1}$ for teff crops [27]. Also, processes like volatilization, leaching, and surface run-off can reduce the available N for the plant, thus lowering NUE [28] [29]. Therefore, improving NUE in crop production is a crucial step in solving the triple challenges; food security, production costs, and environmental pollution [30].

Understanding the crop response and NUE to nitrogen fertilizer application is an important aspect of developing a strategy of site-specific soil nutrient management and optimized fertilizer recommendation [11]. Several studies conducted in Ethiopia focus on the influence of N-application on a single crop and only limited information is available regarding a summarized effect of N-fertilizer on yield and NUE of cereal crops. Therefore, the present meta-analysis study was adopted to elucidate the magnitude of the effect of nitrogen fertilizer on five major cereal crops and NUE with the objectives of 1) evaluating the effect of N fertilization on the yield response of cereal crops; 2) assessing its influence on NUE and 3) examining different potential factors affecting the yield response of the cereal crops in Ethiopia.

## 2. Materials and Methods

In the present study, the effect of N-application on yield and the NUE of the top five cereal crops (maize, teff, wheat, barley, and sorghum) was evaluated. The overall effect of nitrogen fertilizer on yield and NUE and the magnitude of yield response due to different explanatory factors was presented using a quantitative approach.

### 2.1. Data Collection

Peer-reviewed articles published from 1996 to 2020 were accessed from Google Scholar, ScienceDirect, ResearchGate, and Francis and Taylor databases. We used the search string (maize* OR corn* OR wheat* OR sorghum* OR teff* OR barley*) AND (nitrogen* OR nitrogen fertilizer* OR nitrogen use efficiency*) AND (yield*) AND (Ethiopia*). For a study to qualify in this meta-analysis, the following selection criteria had to be met:

- the study was conducted in the field, not pot or greenhouse experiments
- each treatment had a minimum of three replications
- the study reported grain yield and/or NUE
- the experiment was conducted in Ethiopia, and
- experimental and control treatments were applied to the same agricultural site and system.

Results presented in graphs were extracted using GetData Digitizer 2.26 software (http://getdata-graph-digitizer.com/). Overall, 82 studies that met the aforementioned criteria qualified for the final database (see Table 1 and Table S1 in supplementary information). Finally, the experimental sites of the studies included in this meta-analysis were plotted using ArcMap 10.4 (ESRI, 2018) (Figure 1).

### 2.2. Explanatory Variables

Relevant variables were dissected and included in our database to assess the magnitude of yield response (Table 2). The major explanatory variables such as mean annual precipitation (MAP), mean annual temperature (MAT), N-application rate, soil texture, pH, initial soil organic carbon (SOC), and available phosphorous (AP), were categorized into different groups/levels to evaluate their effects on

**Table 1.** Summary of data used in the meta-analysis.

| Crops | Number of studies | n | Minimum | Maximum | Treatment yield (mean ± SD) |
|---|---|---|---|---|---|
| Barley | 14 | 151 | 805.6 | 9804 | 3111 ± 1539 |
| Maize | 17 | 257 | 1494 | 10,900 | 5627.6 ± 2298 |
| Sorghum | 12 | 136 | 386 | 5929.7 | 2997.5 ± 1025 |
| Teff | 13 | 129 | 663.6 | 3680 | 1670.1 ± 640.6 |
| Wheat | 26 | 341 | 1087.8 | 8161 | 3781.5 ± 1298.8 |
| Overall | 82 | 1014 | 386 | 10,900 | 3775.8 ± 2006.4 |

n: number of observations; treatment yield: +N yields; minimum, maximum and the average treatment yield was expressed in $kg \cdot ha^{-1}$.

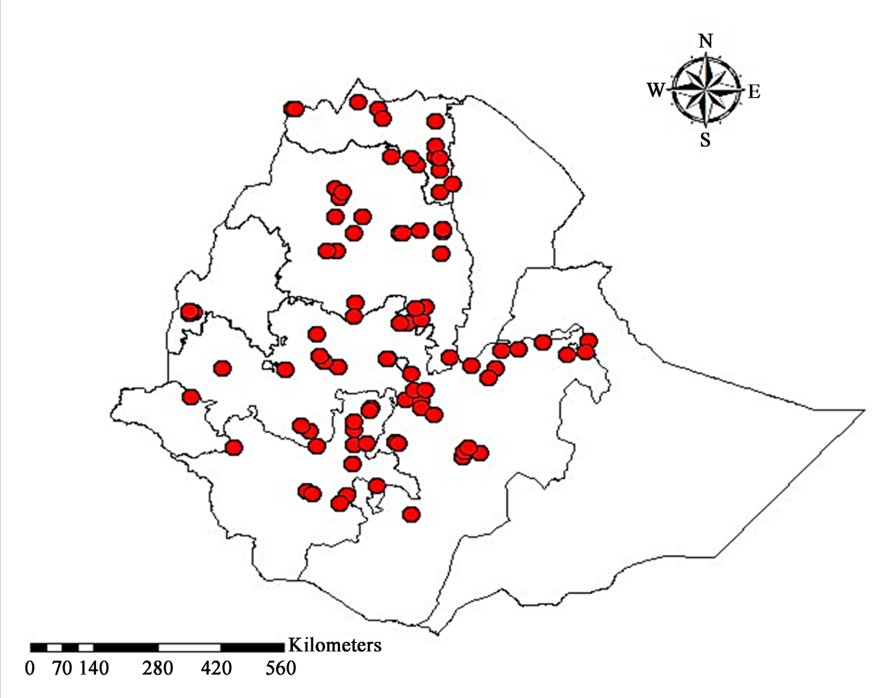


**Figure 1.** Geographical location of the studies included in the meta-analysis.

**Table 2.** Categorization of explanatory variables.

| Variables | Groups | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| N-rate (kg·ha$^{-1}$) | <30 | 30 - 60 | 60 - 100 | >100 |
| MAP (mm) | <700 | 700 - 1100 | >1100 | |
| MAT (˚C) | <16 | 16 - 22 | >22 | |
| Soil texture | Clay | Loam | Sand | |
| Soil pH | <6 | 6 - 7 | >7 | |
| AP (mg·kg$^{-1}$) | Extremely low | Low | Moderate | High |
| SOC (g·kg$^{-1}$) | Extremely low | Low | Moderate | High |

yield under N-fertilizer application. The annual temperature ranged from 11.6˚C to 33.5˚C, whereas MAP ranged from 249.2 to 1800 mm. The percentage clay content was used to categorize the soil textural classes if it was not directly indicated in the study according to [31]. The soils with a clay content below 20%, between 20% - 32%, and >32% were categorized under sandy, loamy and clayey soils, respectively. The percentage of soil texture included in this study was 75.38%, 21.61%, and 3% of clay, loam, and sandy soils, respectively. If the study has reported soil properties of different soil layers (depth), only the topmost layer (0 - 20 cm) was considered. The AP (mg·kg$^{-1}$) and SOC (g·kg$^{-1}$) were categorized as extremely low (≤6), low (6 - 12), moderate (12 - 18) and high (>18), respectively. The NUE, agronomic use efficiency (AE) (the increase in grain yield per unit of fertilizer N applied), and PFP (the ratio of treatment yield to N-inputs) were estimated accordingly.

### 2.3. Data Manipulation and Statistical Analysis

The percentage yield response, the yield obtained from the application of nitrogen fertilizer over control, was estimated as indicated in Equation (1). In order to determine the robustness of the study, sensitivity analysis of the response ratio (RR) *i.e.*, the ratio between the yield on the nitrogen applied plot and control plot, was performed, using the standard procedure to evaluate the overall effect sizes as given in Equation (2). The RR distribution of cereal yield response under N-application is not a typical normal distribution ($p < 0.05$) (**Figure 2**) and therefore, we have used a non-parametric Kruskal-Wallis one-way analysis of variance on ranks to evaluate the differences within two sub-groups of each indicator as indicated in [32].

$$\%\ YR = \left(\frac{Yt - Yc}{Yc}\right) * 100 \tag{1}$$

$$\ln(RY) = \ln\left(\frac{Yt}{Yc}\right) \tag{2}$$

where $YR$, $Yt$, and $Yc$ are yield responses, the grain yield of N-applied and N-omitted (control) yield, respectively.

The meta-analysis was performed in SPSS statistic version 22 and all plots

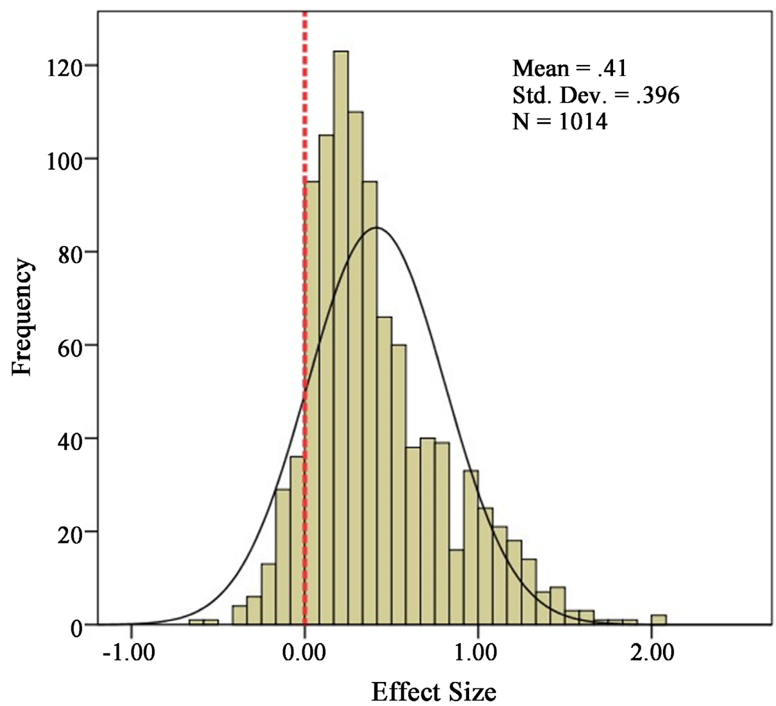


**Figure 2.** The frequency distribution of the response ratio (the effect of nitrogen fertilization on five cereal crops in Ethiopia).

were designed in Sigma-Plot version 12.5 software. The mean effect size and bias-corrected and accelerated/BCA *i.e.*, the 95% confidence interval (CI) for each categorical variable, were generated by bootstrapping at 4999 iterations in SPSS software. Differences between treatments (N-applied) and controls (N-omitted) were considered as significant ($p < 0.05$) if the 95% CI did not cross the line of zero effect (either a significant increase or decrease) and non-significant if it crosses the line of zero effect.

## 3. Results

### 3.1. Yield Variations in Response to N-Application

Overall, the application of nitrogen fertilizer significantly ($p<0.05$) lifted the average yield of all the crops to 3775.8 kg·ha$^{-1}$ (64.8%) when compared to the control treatments which had 2593.3 kg·ha$^{-1}$ (Figure 3). The overall yield response for all the crops was 1180.9 kg·ha$^{-1}$, with wheat having 1545 kg·ha$^{-1}$; maize, 1454 kg·ha$^{-1}$; barley, 1155 kg·ha$^{-1}$; sorghum, 499.8 kg·ha$^{-1}$, and teff, 421.4 kg·ha$^{-1}$ higher than their controls (Figure 4(a)). This clearly indicates that wheat responded more (96.5%) to N-application followed by barley, 84.36%; teff, 50.48%; maize, (40.7%); and sorghum, 23% (Figure 4(b)).

### 3.2. Nitrogen Use Efficiency in Response to N-Application

The $AE_N$ and $PFP_N$ to nitrogen fertilization were presented in Figure 5(a) & Figure 5(b). Overall, $AE_N$ and $PFP_N$ were significantly influenced by N-application.

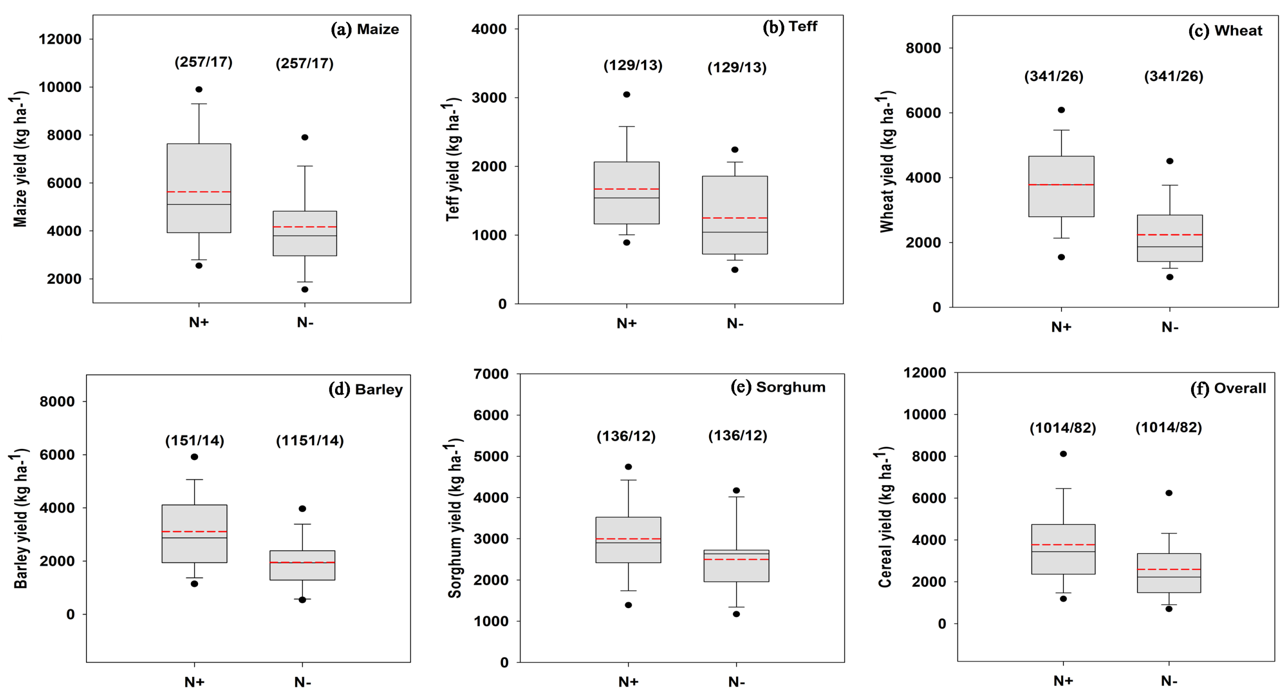


Figure 3. Grain yield responses of maize, teff, wheat, barley, sorghum, and their overall (a)-(f) to applied N fertilizer when compared with their control treatments. The red dotted and black solid lines represent mean and median values, respectively. Numbers in the bracket represent observation and study, respectively. $N^+$, with nitrogen; $N^-$, without nitrogen.

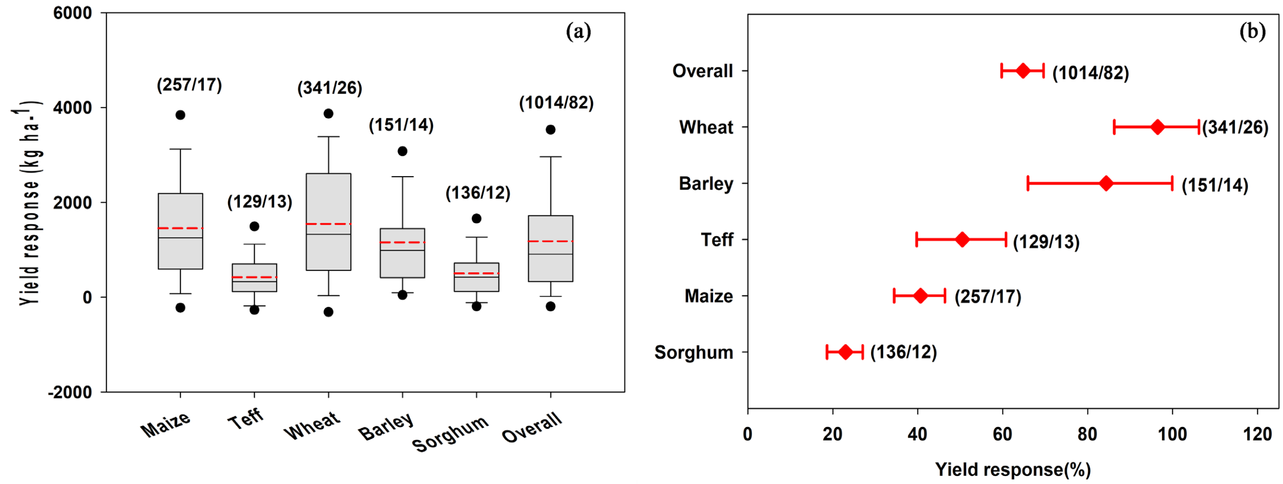


**Figure 4.** Yield variations (kg·ha$^{-1}$) (a) across five cereal crops and their percentage yield responses (b) to applied N-fertilizer. The red dotted and black solid lines represent mean and median values, respectively. Numbers in the bracket represent observation and study, respectively.

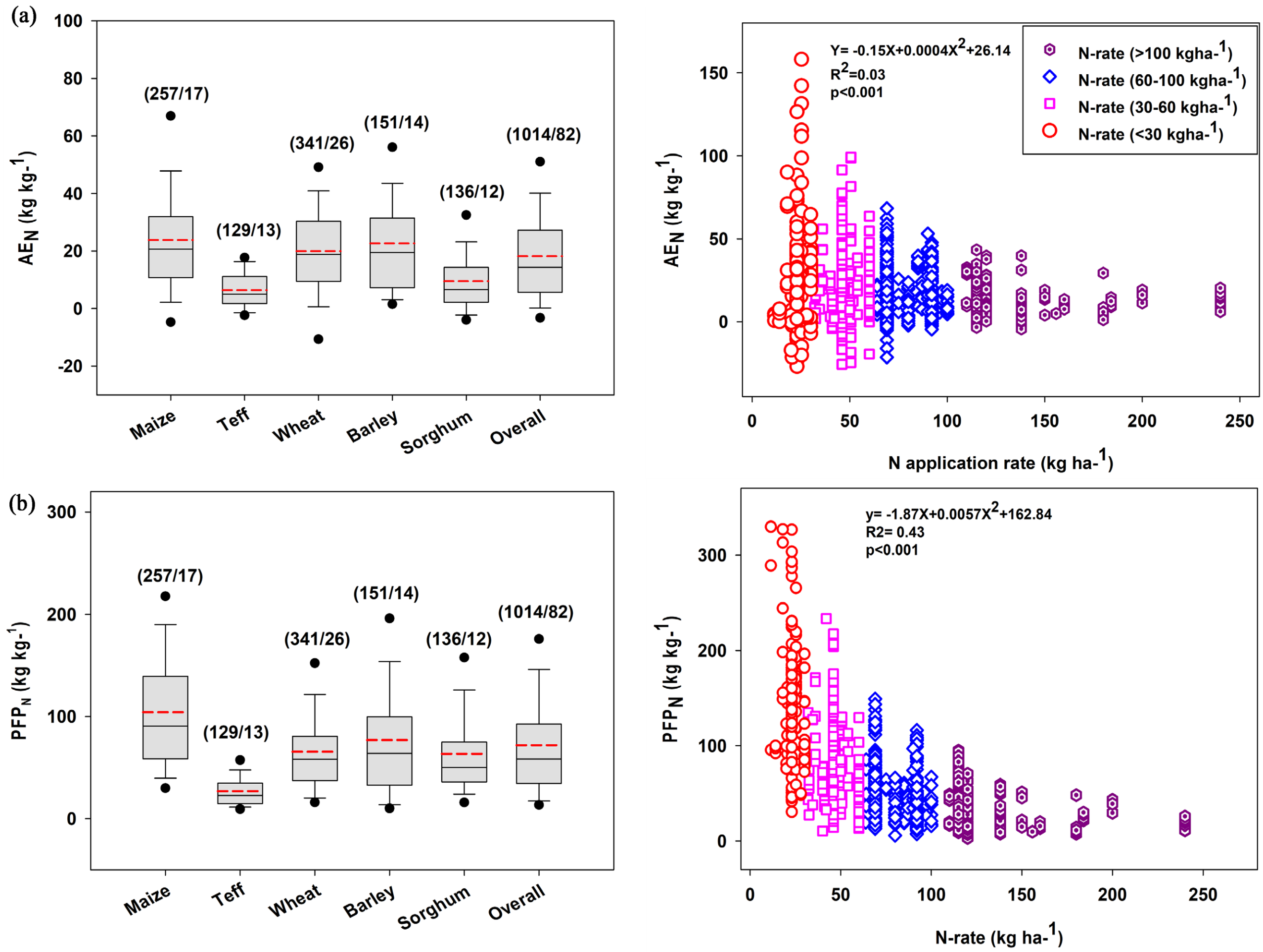


**Figure 5.** Agronomic use efficiency (a) and partial factor productivity (b) as affected by N-application for the five cereal crops. The red dotted and black solid lines represent mean and median values, respectively. Numbers in the bracket represent observation and study, respectively.

The average $AE_N$ and $PFP_N$ values across all studies were 18.2 and 71.81 kg·kg$^{-1}$, respectively. Also, $AE_N$ and $PFP_N$ were declined with the increase of the N fertilizer. At N rates of <30, 30 - 60, 60 - 100, and >100 kg·ha$^{-1}$, the $AE_N$ values were 23.42 kg·kg$^{-1}$, 19.21 kg·kg$^{-1}$, 16.43 kg·kg$^{-1}$, and 14.35 kg·kg$^{-1}$, while $PFP_N$ were 139.5 kg·kg$^{-1}$, 74.14 kg·kg$^{-1}$, 51.93 kg·kg$^{-1}$, and 32.24 kg·kg$^{-1}$, respectively. Moreover, $AE_N$ and $PFP_N$ varied with crop type. The highest $AE_N$ and $PFP_N$ were realized in maize (23.8 and 104.13 kg·kg$^{-1}$) followed by barley (22.65 and 76.9 kg·kg$^{-1}$), and wheat (19.96 and 65.51 kg·kg$^{-1}$), respectively, while the lowest $AE_N$ and $PFP_N$ were recorded in sorghum (9.46 and 63.44 kg·kg$^{-1}$) followed by teff (6.36 and 26.92 kg·kg$^{-1}$), respectively.

### 3.3. Different Explanatory Variables on Grain Yield

Mean annual temperature, MAP, nitrogen application rate, soil texture, soil pH, SOC, and AP had a significant impact on cereal yield. The yield of five cereal crops could linearly and significantly increase with N-application rate and was maximum at >100 kg·ha$^{-1}$ (123.9%) and lowest (28.9%) where <30 kg·ha$^{-1}$ of N was applied (**Figure 6(a)**). The lower temperatures of <16˚C resulted in a 71.8% yield increase, while a 52.4% yield increase was realized at temperatures above 22˚C (**Figure 6(b)**). Also, N application increased crop yields by 80.2% and 79.9% with a MAP of <700 mm and >1000 mm, respectively (**Figure 6(c)**).

The result revealed that the cereal yield response due to N-application was considerably higher at the pH range of 6 - 7 (77.2%) than at pH of <6 (58%) and >7 (58.3%) (**Figure 7(a)**). The highest yield response was observed in clay soil (75.5%) followed by loam soil (72.2%), while lowest in sandy soil (57.1%) (**Figure 7(b)**). Soil AP concentration resulted in minimum and maximum yield responses of 101.6% and 29.6%, respectively (**Figure 7(c)**). Moreover, N-application significantly increased yield by 92.4% where the initial SOC concentration was low, and by 50% where the initial SOC was extremely low (**Figure 7(d)**).

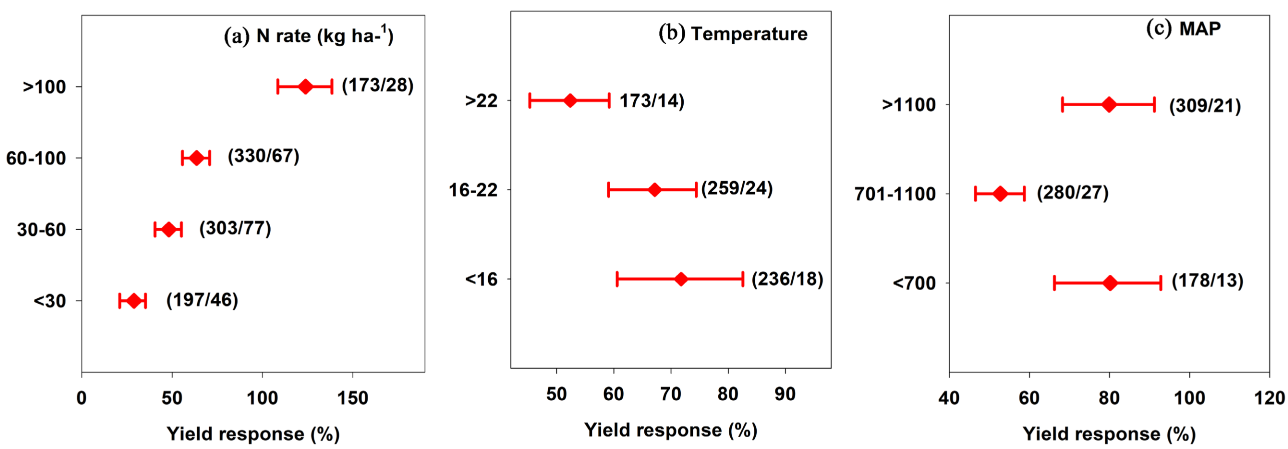


**Figure 6.** Effect of varying N-rate, temperature, and mean annual precipitation (MAP). Error bars represent a mean value at 95% CI. Numbers in the bracket represent observation and study, respectively.

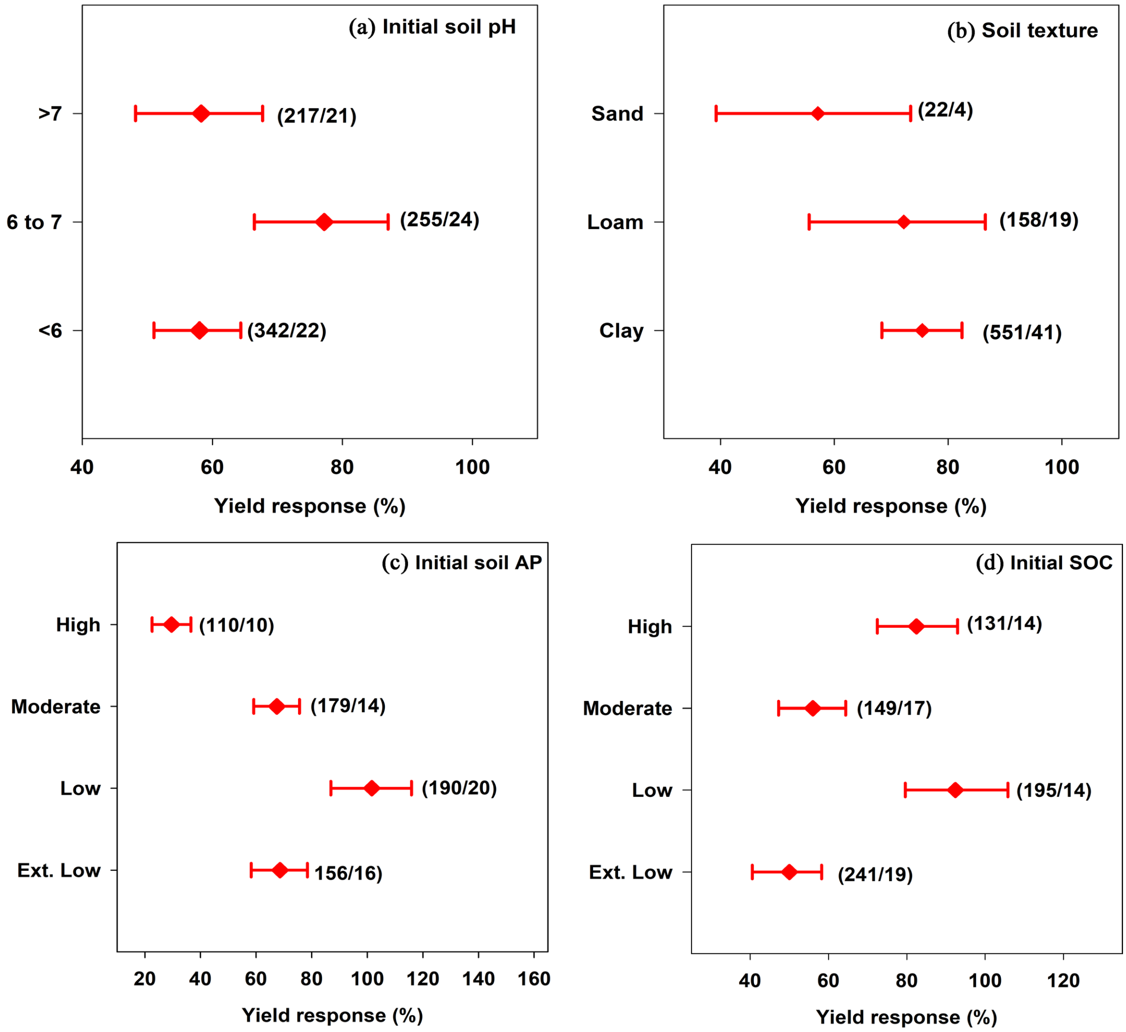


**Figure 7.** Effect of N-application on yield under different levels of soil pH, soil texture, initial soil AP, and initial SOC. Error bars represent a mean value at 95% CI. Numbers in the bracket represent observation and study, respectively.

## 4. Discussion

### 4.1. Grain Yield in Response to N-Fertilizer

In the present meta-analysis study, N-application significantly increased grain yield in maize, teff, wheat, barley and sorghum by 64.8% overall (Figure 3 and Figure 4). The increase of crop yield under N application is due to the critical importance of nitrogen fertilizer as a macronutrient in the agricultural production system and its potential to augment the low nitrogen levels in soil [33]. It is also related to the high importance of N fertilizer in enhancing plant leaf area, and photosynthesis efficiency; which resultantly enhance harvest index, plant dry matter, and crop yield [2] [22]. Rational nitrogen fertilization on agricultural fields has paramount importance to improve soil and crop productivity, while overdose leads to deterioration of soil quality [29] [34]. In line with the present findings, several studies reported the positive response of crop yield to nitrogen application [2] [31] [35] [36]. Abera *et al.* [2] reported that maize crop fertilized with half (55 kg·ha$^{-1}$) and full recommended (110 kg·ha$^{-1}$) of N-fertilizer in Ethiopia has a grain yield advantage of 18% to 209% and 18% to 254% over the control, respectively. Also, a meta-analysis study conducted in Zimbabwe revealed a positive and significant yield response of 33.7% under N-application over the control [33].

### 4.2. Nitrogen Use Efficiency

We found the overall $AE_N$ and $PFP_N$ of 18.2 and 71.81 kg·kg$^{-1}$, respectively, which also largely varied with N rate and crop type. However, our results show an overall inverse relation between NUE and N-application rate (**Figure 5(a)** and **Figure 5(b)**). This indicates N applied at low rates is efficiently utilized by the crop for biomass accumulation while continuous application of N beyond the optimum rate results in reduced N use efficiency and yield determinant factors other than N becomes more limiting when the crop approaches its maximum yield potential [27] [37]. Plants cannot absorb nutrients applied in excess due to their absorption mechanisms becoming oversaturated. Under these conditions, there exists a high chance of unabsorbed N loss to the environment through different mechanisms such as volatilization and leaching. The variation of NUE across the studied crops could be related to genotypic variation, environment, soil indigenous nutrient supply, management methods and nutrient application rate [11] [23] [38].

The variability in crop response, soil fertility differences, and climatic conditions and other factors makes the management and improvement of NUE more difficult. More importantly, understanding such variabilities is highly essential to design area-specific nutrient management practices. Several approaches have been developed to improve NUE in agriculture such as integrated soil fertility management [38], nutrient stewardship [39] [40], use of organic fertilizer [41], root-zone nutrient management [42], integrated soil-crop system management (ISSM) [43], using nutrient use efficient cultivars [44], precision farming [45] and so on. Overall, rationalization of the fertilizer use and adoption of an integral management approach based on an inclusive understanding of the yield and NUE limiting factors is an important step to achieve high crop productivity and high NUE [2] [25].

### 4.3. Source of Variation in Yield Responses

The present study revealed that the cereal yield response to N fertilizer was largely positive and significant, but the magnitude of yield response varied based on N-supply rate, MAP, MAT, soil texture, pH, initial SOC, and AP (**Figure 6** and **Figure 7**). The observed linear relation between N-rate and grain yield (**Figure 6(a)**) emphasizes the need to increase yields by applying high rates of nitrogen than the average current N-application rate in Ethiopia. Gotosa *et al.* [33] found a linear relation of maize yield with nitrogen input rate, and the highest yield response was revealed at N-rate > 100 kg·ha$^{-1}$, which was in line with the present findings.

Temperature is an important yield determining factor and its deviation from the optimum due to climate change or other factors negatively impacts crop productivity. A study conducted in China revealed that a unit increase of climate warming resulted in a reduction of maize yield by 2.6% [46]. However, the magnitude of change in yield varies depending on location, season, and soil inherent fertility status [46], which was concordant with our finding (**Figure 6(b)**). MAP is among the major factors that affect crop production, particularly in rain-fed regions [47], where there is a scarcity or lack of irrigation systems. For example, in Ethiopia, despite the smallholder accounts for over 95% of the total maize area and production, the irrigated areas account for only 1% of the total [17]. The distribution and pattern of rainfall considerably influence the grain yield and NUE [11] [48]. However, the observed increase-decrease-increase yield response trends in MAP (**Figure 6(c)**) might be related to the variation in water requirements of each crop.

The soil pH is a major indicator that plays a significant role in the availability of soil nutrients and also affects plant nutrient uptake and use efficiency. The higher yield response in soils with pH values ranging from 6-7 (**Figure 7(a)**) is implying the profound effect of soil pH on soil nutrient availability. In this range, most soil nutrients are optimally available to plants. Chen *et al.* [49] found a higher yield response in the near-neutral pH range (6.6 to 7.3). Regarding the soil texture, higher yield response was observed in clay soils followed by loamy soils (**Figure 7(b)**). The reason is the potential of clay and loamy soils to hold water and sequester organic carbon. Whereas, the lower yield response of sandy soil is due to its high leaching potential, low clay content, poor water retaining potential, and poor OM content [33] [50]. The highest yield response in low SOC (6 - 12 g·kg$^{-1}$) and AP content (6 - 12 mg·kg$^{-1}$) could be due to the potential of nitrogen fertilizer to improve infertile soils and resultantly crop productivity (**Figure 7(c)** and **Figure 7(d)**). The supply of soil nutrients in already fertile soils slightly enhances or even declines the grain yield. Another study revealed a higher yield increase under P-fertilizer application when the soil phosphorous is low [51] and under controlled-release nitrogen application when the SOC content is low [52]. Therefore, it was observed that the N-application in Ethiopia significantly increases crop yield, although the magnitude is affected by several explanatory factors and crop type.

## 5. Conclusion and Future Perspectives

The result showed that the application of N significantly increased yield in all the crops studied by 64.8% at an average N-application rate of 72.9 kg·ha$^{-1}$. The downtrend of $AE_N$ and $PFP_N$ was observed with the increase of N-rates. Overall yield response was varied under different explanatory factors such as MAP, MAT, N-application rate, soil texture, soil pH, AP, and SOC. The yield response was higher at a high N-application rate, low SOC and AP contents. We, however, recommend the application of optimum N-fertilizer (>100 kg·N·$ha^{-1}$), especially in infertile soils, to enhance cereal crop productivity in Ethiopia. In this study, several important factors that influence the yield response were not evaluated due to insufficient reporting across the studies. Therefore, future studies are needed to focus on a comprehensive selection of variables that influence crop yield and nitrogen use efficiency.

## Acknowledgements

The authors greatly acknowledge China Agricultural University (CAU) and Sino-Africa STB project for the vital support and conductive environment to conduct the study. We also acknowledge the anonymous reviewers for their constructive and directive suggestions.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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## Supplementary Information

**Table S1.** List of articles included in the present meta-analysis study with a parameter of interest.

| Author and year of publication | Journal site | Types of crops | Parameters collected |
|---|---|---|---|
| Abdenna D., *et al.*, 2014 | J. of Environment and Human | Wheat | ST, pH, SOC, TN, AP, Yield |
| Assefa M., *et al.*, 2015 | Int. Journal of Plant & Soil Science | Wheat | Temp, ST, pH, SOC, TN, AP, Yield |
| Woyema A., Bultosa G. and A. Taa, 2012 | African J. of Food, Agriculture, Nutrition and Development | Wheat | Temp, Yield |
| Nano Alemu, 2017 | Journal of Agricultural Science | Wheat | Temp, ST, pH, SOC, TN, AP, Yield |
| Fresew B., *et al.*, 2018 | Agriculture and Food Security | Wheat | ST, pH, SOC, TN, AP, Yield |
| Melesse Harfe, 2015 | African J. of Agricultural Research | Wheat | |
| Beyenesh Z., and Nigussie D., 2017 | Int. J. of Life Sciences, | Wheat | Temp, ST, Yield |
| Tamado T., Dawit D., and J.J. Sharma, 2015 | East African Journal of Sciences | Wheat | Temp, ST, pH, SOC, TN, AP, Yield |
| Wubishet A. and Tilahun B., 2016 | Plant | Wheat | Yield |
| Wogene Solomon and Agena Anjulo, 2017 | Int. Journal of Scientific and Research Publications, | Wheat | ST, pH, SOC, AP |
| Sakatu Hunduma, 2017 | J. of Natural Sciences Research | Wheat | Temp, yield |
| Tilahun Chibsa *et al.*, 2016 | American Journal of Research Communication | Wheat | Temp, RF |
| Adamu Molla, 2018 | Journal of Agricultural Science | Wheat | Temp, ST, pH, SOC, TN, AP, Yield |
| Tilahun Abera and Tamado Tana, 2019 | African Journal of Plant Science | Wheat | Temp, pH, Yield |
| Nano A., J.J. Sharma and Firdissa Iticha, 2016 | World Journal of Agricultural Sciences | Wheat | ST, pH, SOC, TN, AP, Yield |
| Taye Belachew and Yifru Abera2, 2011 | Journal of Biodiversity and Environmental Sciences (JBES) | Wheat | Temp, Yield |
| Alemu D., Ketema B., Tesfaye S., 2019 | International Journal of Plant Breeding and Crop Science | Wheat | Temp, ST, pH, SOC, TN, AP, Yield |
| Mulugeta Eshetu, *et al.*, 2017 | Int. Journal of Science and Qualitative Analysis | Wheat | Yield |
| Sofonyas D., Lemma W. and Selamyihun K., 2018 | Ethiop. J. Agric. Sci | Wheat | Temp, ST, pH, SOC, TN, AP, Yield |
| Bereket H., *et al.*, 2014 | Agr., Forestry and Fisheries | Wheat | Temp, ST, pH, SOC, TN, AP, Yield |
| Fresew B., *et al.*, 2018 | Agriculture and Food Security | Wheat | ST, pH, SOC, TN, AP, Yield |
| Tolcha T., *et al.*, 2020 | Plant | Wheat | Temp, ST, pH, SOC, TN, AP, Yield |
| Yohannes E. and Nigussie D., 2019 | J. of Natural Sciences Research | Wheat | Temp, ST, pH, SOC, TN, AP, Yield |
| Arega G., *et al*, 2013 | Int. J. of Agronomy and Plant Production | Wheat | Yield |
| FIKIRTE G., 2018 | MSc thesis to Gondar University, Ethiopia | Wheat | Temp, ST, pH, SOC, TN, AP, Yield |

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|---|---|---|---|
| Fenta A., 2018 | ARPN J. of Agr. and Biological Science | Teff | Temp, pH, Yield |
| Ayalew B. *et al.*, 2016 | ICARDA Project | Teff | ST, Yield |
| Yared T., Girma T., and Kabna A., 2019 | American Journal of Agricultural Research | Teff | ST, pH, SOC, TN, yield |
| Temesgen K., 2019 | Advances in Crop Science and Technology | Teff | Temp, ST, pH, SOC, TN, AP, Yield |
| Kefyalew A., Tilahun F., Tadesse H., 2017 | Journal of Biology, Agriculture and Healthcare | Teff | Yield |
| Tamirat W., 2019 | Int. Journal of Plant & Soil Science | Teff | Temp, ST, pH, SOC, TN, AP, Yield |
| Haftamu G., Mitiku H. and Charles F., 2009 | Mekelle University | Teff | Yield |
| Teshome M., Wassie H., Sofiya K., 2019 | Int. J. of Advances in Agr. Science and Technology | Teff | Temp, ST, pH, SOC, TN, AP, Yield |
| Fissehaye M., *et al.*, 2009 | JOURNAL OF THE DRYLANDS | Teff | Temp, ST, pH, SOC, TN, AP, Yield |
| Abraha A., 2013 | MSc thesis to Haramaya Univesity, Ethiopia | Teff | ST, pH, SOC, TN, AP, Yield |
| Tsadik T., 2019 | Journal of Soil Science and Environmental Management | Teff | Temp, ST, pH, SOC, TN, AP, Yield |
| Berihanu S., 2019 | Int. Journal of Agriculture and Environmental Research | Teff | ST, pH, SOC, TN, AP, Yield |
| Abebe G., *et al.*, 2020 | African Journal of Agricultural Research | Teff | Temp, ST, pH, SOC, TN, AP, Yield |
| Bayu, W., Getachew A., and Mamo T., 2002 | Acta Agronomica Hungarica | Sorghum | ST, pH, SOC, TN, AP, Yield |
| Sheleme K., *et al.*, 2016 | Advances in Crop Science and Technology | Sorghum | Temp, pH, Yield |
| Nigus D., *et al.*, 2017 | Archives of Agronomy and Soil Science | Sorghum | Temp, ST, pH, SOM, AP, Yield |
| Letemariam D., *et al.*, 2020 | Int. Journal of Research Agriculture and Biosciences | Sorghum | Temp, pH, SOC, TN, AP, Yield |
| Zerihun S., 2016 | Journal of Biology, Agriculture and Healthcare | Sorghum | Temp, ST, pH, SOC, TN, P, Yield |
| Fikadu T., *et al.*, 2018 | OALib | Sorghum | Temp, ST, pH, SOM, AP, Yield |
| Ertiban W., 2016 | ICARDA | Sorghum | Temp, MAP, ST, pH, SOM, TN, AP, Yield |
| Fantaye B.M., 2019 | Journal of Advancements in Plant Science | Sorghum | Temp, ST, pH, SOC, TN, P, Yield |
| Wondimu B., N.F.G. Rethman and P.S. Hammes, 2005 | S. AfT. Tydskr. Plant Grond | Sorghum | ST, pH, SOC, TN, P, Yield |
| Esilaba A.O., *et al.*, 2000 | African Crop Science Journal | Sorghum | Yield |
| Gebrelibanos G. and Dereje A., 2020 | Int. Journal of Agricultural Research | Sorghum | Temp, ST, pH, SOC, TN, AP, Yield |
| Feyera M., *et al.*, 2020 | Nutrient Cycling in Agroecosystems | Sorghum | Yield |
| Geremew T., Kindie, T. and Tolessa, D., 2015 | Journal of Natural Sciences Research | Maize | Temp, ST, pH, SOC, TN, AP, Yield |

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| | | | |
|---|---|---|---|
| Tolera A., Tolessa D., and Dagne W., 2017 | Int. Journal of Agronomy | Maize | Temp, ST, pH, SOC, TN, Yield |
| Abebe and Feyisa, 2017 | Int. Journal of Agronomy | Maize | Temp, ST, pH, Yield |
| Yihenew G., 2015 | Environmental Systems Research | Maize | ST, pH, SOC, Yield |
| Begizew G., Adugnaw M. and M. Getachew, 2018 | Open Journal of Plant Science | Maize | ST, pH, SOC, TN, AP, Yield |
| Wubalem Z., and Parshotam D., 2020 | IOSR Journal of Agriculture and Veterinary Science | Maize | Temp, ST, pH, SOC, Yield |
| Bejigo, Gizaw, 2018 | American Journal of Agriculture and Forestry | Maize | Temp, ST, pH, SOC, TN, AP, Yield |
| Shiferaw T., Anteneh A., and Tesfaye B., 2018 | Ethiop. J. Agric. Sci. | Maize | Temp, pH, SOC, TN, AP, Yield |
| Keyro A., and Zenebe M., 2019 | African Journal of Agricultural Research | Maize | Temp, ST, Yield |
| Besufikad E. and Tesfaye D., 2019 | ACTA Scientific agriculture | Maize | Temp, ST, pH, Yield |
| Yihenew G., 2007 | Ethiopian Journal of Natural Resources | Maize | ST, pH, SOC, AP, Yield |
| Zelalem B., 2013 | African Journal of Agricultural Research | Maize | Temp, ST, pH, SOC, TN, AP, Yield |
| Ewnetie T., *et al.*, 2017 | American Journal of Plant Sciences | Maize | |
| KEYRO A., 2017 | Thesis submitted to AMU, Ethiopia | Maize | Temp, ST, pH, SOC, AP, Yield |
| Yihenew G., 2016 | Environmental Systems Research | Maize | ST, pH, AP, yield |
| Yacob A. and Meshu S., 2015 | Journal of Natural Sciences Research | Maize | Temp, ST, pH, TN, AP, Yield |
| Feyera M., *et al.*, 2020 | Nutrient Cycling in Agroecosystems | Maize | Yield |
| Derebe T., Temesgen D., Habtamu A., 2018 | Int. J. of Research Studies in Agricultural Sciences | Barley | Temp, ST, pH, SOC, TN, AP, Yield |
| Mesfin K. and Zemach S., 2015 | American J. of Agriculture and Forestry | Barley | ST, pH, TN, Yield |
| Admas A., & Fikre H., 2014 | | Barley | Temp, Yield |
| Demisie E., Tamado T., Firdissa E., 2015 | Research & Reviews: J. of Crop Science and Technology | Barley | Temp, ST, pH, SOC, TN, AP, Yield |
| Sofonyas D., *et al.*, 2018 | African J. of Agricultural Research | Barley | ST, pH, SOC, TN, AP, Yield |
| Getachew A., Berhane L., and Paul N., 2013 | Archives of Agronomy and Soil Science | Barley | Temp, pH, SOC, TN, AP, Yield |
| Feyera M., *et al.*, 2020 | Agronomy J. | Barley | Yield |
| Ketema N., and Mulatu K., 2018 | J. of Natural Sciences Research | Barley | Temp, ST, pH, SOC, TN, AP, Yield |
| Dejene K., and Fetien A., 2014 | Momona Ethiopian J. of Science | Barley | Temp, ST, Yield |
| Girma Chala, 2017 | Int. J. of Research in Agr. Sciences | Barley | Temp, ST, pH, SOC, TN, AP, Yield |
| Amare A., and Adane L., 2015 | World J. of Agricultural Sciences | Barley | Temp, ST, pH, SOC, TN, AP, Yield |
| Meharie K., Kindie T., 2019 | J. of Crop Science and Biotechnology | Barley | Temp, ST, pH, SOC, TN, AP, Yield |
| Lake Mekonnen, 2018 | J. of Natural Sciences Research | Barley | Temp, pH, SOC, TN, AP, Yield |
| Woldekiros B., 2018 | J. of Biology, Agri. and Healthcare | Barley | Temp, ST, pH, SOC, TN, Yield |

Note: Temp, ST, MAP, SOC, TN and AP represent temperature, soil texture, mean annual precipitation, soil organic carbon, total nitrogen and available phosphorous, respectively.