Archives of Agriculture and Environmental Science 8(2): 244-249 (2023)
https://doi.org/10.26832/24566632.2023.0802022

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: journals.aesacademy.org/index.php/aaes

REVIEW ARTICLE

Alternative fertilization approaches in enhancing crop productivity and nutrient use efficiency: A review

Solomon Yokamo[1*], Amani Stephen Milinga[2,3] and Buana Suefo[4]

[1]South Agricultural Research Institute (SARI), Hawassa, ETHIOPIA
[2]Hainan University, Hainan, CHINA
[3]Tanzania Smallholders Tea Development Agency, Dar es Salaam, TANZANIA
[4]Polythecnic Institute Mártir Cipriano of Nacuxa, Mossuril, Nampula, MOZAMBIQUE
[*]Corresponding author's E-mail: solomonyokamon@gmail.com

ARTICLE HISTORY

Received: 18 April 2023
Revised received: 07 June 2023
Accepted: 18 June 2023

Keywords

Alternative fertilization options
Crop yield
Enhanced efficiency fertilizer
Micronutrients
Nutrient use efficiency
Organic fertilizer

ABSTRACT

The greatest challenge of our time is to meet the global food demand by producing enough food without harming the environment. Over application and misuse of synthetic fertilizer is a major challenge that results in lower fertilizer use efficiency (FUE), stagnated crop yield, and environmental pollution. In this review study, three alternative fertilization options (AFOs), such as the use of organic fertilizer enhanced-efficiency fertilizer (EEFs), and secondary, and micronutrient fertilizers were evaluated. The adoption of appropriate fertilization practices was believed to improve crop yield and FUE over the conventional fertilization approach. As of late, the use of organic fertilizers has received more attention as a better alternative to counter the challenges posed by the inappropriate use of chemical fertilizers. The formulation of slow or controlled-release fertilizers contributes to preventing nutrient losses by slowing down nutrient release patterns in the soil and allowing better synchrony between crop nutrients requirement and nutrient supply. The use of secondary macronutrients and micronutrient also has considerable importance to improve nutrient uptake, grain yield, and quality. In summary, the review result showed that the adoption of AFOs can enhance crop yield and nutrient use efficiency.

Citation of this article: Yokamo, S., Milinga, A. S., & Suefo, B. (2023). Alternative fertilization approaches in enhancing crop productivity and nutrient use efficiency: A review. *Archives of Agriculture and Environmental Science*, *8*(2), 244-249, https://dx.doi.org/10.26832/24566632.2023.0802022

INTRODUCTION

Chemical fertilizer plays a critical role in household food security. The application of chemical fertilizer provides one or more essential soil nutrients for the growth and development of plants. Nitrogen, phosphorous, and potassium are the three most widely used soil nutrients (Dhillon *et al*., 2019). Nitrogen (N) is one of the most important yield-limiting nutrients in agriculture. It is also one of the most mobile and soluble element. It is required in large amounts than any other soil nutrient. Urea is the most commonly used N fertilizer in the world, which is characterized by high volatility. It has a high solubility tendency, low thermal stability and molecular weight, and is easily subject to loss from soil-plant systems through different mechanisms such as volatilization, run-off, and leaching (Vejan *et al*., 2021). The urea lost through these processes causes serious environmental threats such as water eutrophication, air pollution, and land degradation. Phosphorus (P) is an essential macronutrient for plant growth and development, helps with root formation and development, promotes maturation, and helps plants resist disease. It is a limiting resource for crop production and its rational management in agriculture is important to enhance yield and phosphorous use efficiency (PUE). Also, the percentage of P consumption is massively hampered due to volatilization and leaching of nutrients, which resultantly causes environmental, health, and economic concerns (Vejan *et al*., 2021). Potassium is the third important soil nutrient that helps plant to resist disease, and enhance crop yield and quality. It also plays a major role in the elongation of cells and regulating the opening and closing of stomata (Yokamo *et al*., 2022).

The consumption of synthetic fertilizer in crop production is increasing due to the increased quest for food and thereby feeding hunger. In the year 2014/15, the global fertilizer use reached about 181.9 Mt (Heffer *et al*., 2017), among this amount, cereal crops consume nearly half (49.3%). This is also a reason for the 340% increase in world cereal production in the past 59 years (1961-2019) (Yokamo *et al*., 2022). Despite their intensive use, over application and misuse of these soil nutrients results in several environmental threats, particularly in intensive production regions such as China and India and some developed and quickly developing countries. For example, the N fertilizer input in an intensive wheat-maize cropping system in China reaches about 588 kg ha^{-1} (Vitousek *et al*., 2009). Plants recover only about 361 kg ha^{-1} yr^{-1} and the remaining +227 kg ha^{-1} will either remain in the soil or be lost from the agricultural field through run-off, volatilization, and/or leaching, which then affects environmental sustainability. Comparatively, the fertilizer consumption in the least developed countries, for example in Sub-Saharan Africa (SSA) is extremely low i.e., it is about 20 kg ha^{-1}, which is significantly lower compared to the world average of 136.8 kg ha^{-1} (World Bank, 2021). The reason for lower consumption is related to high cost, limited accessibility and availability at the right time and rate of chemical fertilizer, poor access to credit services, and information gaps (Legesse *et al*., 2019; Chianu *et al*., 2012).

The macro and micronutrients removed from agricultural soils through crop harvest and other mechanisms need replacement by supplying chemical and organic fertilizer or through biological processes like nitrogen fixation (Vitousek *et al*., 2009). In Africa, nutrient loss (i.e., through crop harvest and other loss mechanisms) ever exceeds the input rate and which exacerbates environmental degradation. For example, the N input rate in Western Kenya is about 7 kg ha^{-1}, whereas the total agronomic output is about 59 kg ha^{-1} and its N balance (agronomic N input minus harvest removal) is about -52 kg ha^{-1} (Vitousek *et al*., 2009). Additionally, the N and K balances in Ethiopian soils were -23±73 and -7±64 kg ha^{-1}, respectively (Van Beek *et al*., 2016). However, overuse, misuse, and inadequate/marginalized use of these soil nutrients negatively affect agricultural production and reduce the efficiency of nutrient use. Moreover, the application of fertilizers without considering the indigenous nutrient supply potential of the soil, poor synchrony between nutrient supply and plant nutrient requirement (Sharma and Bali, 2018), blanket recommendation, and supplying a large dose of chemical fertilizer at pre-plant as insurance affects nutrient use efficiency (NUE) and sustainable crop production. Also, the long-term use of sole chemical fertilizer is known to not only degrade soil quality and reduce crop yields but also reduce NUE and exacerbate environmental degradation.

Improvement of crop yield and NUE simultaneously in agriculture has become a major challenge of our time with mounting food demand, natural resource depletion, and environmental worsening (Ding *et al*., 2018). The NUE (i.e., an index of a plant's ability to uptake soil-available nutrients) was reportedly low in field crops. For example, NUE showed a dramatic drop over time and was maintained at about 25% in China (Zhang *et al*., 2015). Also, the world P and K use efficiency in cereal crops remained at 16% (Dhillon *et al*., 2017) and 19% (Dhillon *et al*., 2019), respectively. This reveals that more than three-fourths of unaccounted N, P, and K remain in the soil or be lost from the soil-plant system, which consequences in several environmental effects. As NUE has multidisciplinary (agronomic, economic, and environmental) implications, its improvement in the field crops remains an important step in maintaining sustainable production while reducing production costs and environmental consequences. In this study, three major AFOs were examined and their impacts on crop yield and NUE were elucidated. A comprehensive literature search was conducted from different published sources; the FAOSTAT database was also used to show the nutrient consumption trends over the decades.

Nutrient consumption trends from 1961 to 2019

Three major nutrients (N, P, and K) consumption trends across four countries from 1961-2019 were illustrated in Figure 1. The result showed that N consumption is linearly increasing in India and Brazil, while it showed a declining trend in China since 2015. In Kenya, N, P, and K fertilizer consumption remains nearly constant and did not show a considerable change in the past 59 years. The reason for the declining trend of fertilizer use in China since 2015 is due to the government's "Zero Fertilizer Growth" action plan for national fertilizer use by 2020 (Liu *et al*., 2016). The objective of this campaign is to halt chemical fertilizer use below 1% (from 2015-2019) and with no more increase starting from 2020 without declining crop yield.

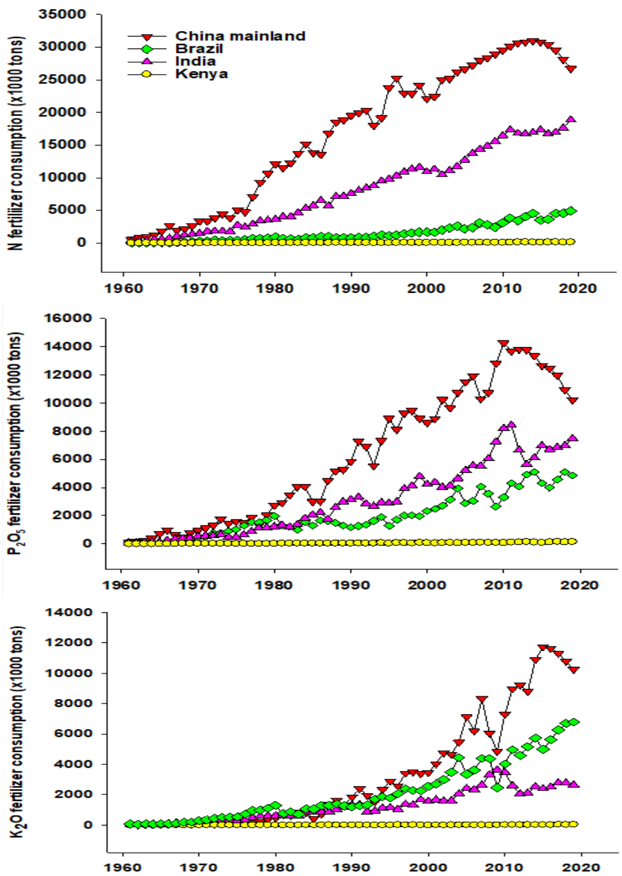

Figure 1. *A 59-years (1961-2019) fertilizer N (a), P_2O_5 (b) and K_2O (c) consumption (in 1000 tons). Data was collected from FAOSTAT database.*

Alternative fertilization options (AFOs)

Intensified crop and animal production become a common practice to supply sufficient food for the booming population (Zhang *et al.*, 2020; Zhang *et al.*, 2020). For example, cereal crop production has increased by 340% in the past 59years. The increase is mainly related to the intensive use of chemical fertilizer (9.45, 4, and 4.34-fold of N, P_2O_5, and K_2O consumption since the aforementioned period (Yokamo *et al.*, 2022) and wide adoption of high-yielding varieties, pesticide use, and irrigation. It is clear that increasing the fertilizer rate enhances crop yield to a specific level, but the yield increase becomes negligible and starts declining with the continuous increase of fertilizer beyond the optimum level. Thus, the remaining fertilizer either remains in the soil or is lost from the plant-soil systems causing a variety of environmental threats such as air pollution due to gaseous emissions, eutrophication, and land degradation. It was reported that the adoption of organic inputs, slow-release fertilizer, green manure, and secondary micronutrient fertilizer could enhance crop yield and fertilizer use efficiency while minimizing nutrient loss. The meta-analysis study conducted in China revealed that the adoption of AFOs of organic fertilizer, slow-release fertilizer, green manure, straw return, and secondary/micronutrient fertilizer enhanced the rice yield by 7.8%, 7.4%, 6.7%, 5.4% and 4.6% against the conventional fertilization, respectively (Ding *et al.*, 2018). Similarly, the adoption of AFO enhanced the N recovery efficiency, agronomic efficiency, and partial factor productivity by 6-34.8%, 10.2-29.5%, and 4.7-6.9% over conventional fertilization methods. These findings reveal the potential of AFOs to reverse the aforementioned challenges and maintain sustainable production.

Use of organic inputs

Optimization of nutrient use through alternative management options is important for maintaining soil quality and sustainability of agricultural production. Over the past few decades, intensified agriculture created a bounty loss in soil fertility. On this basis, sole organic inputs or in combination with chemical fertilizer have been proposed as a decisive option over sole chemical fertilization. Organic amendments are taken as a win-win approach for achieving food security and climate change mitigation. Organic fertilizer includes all the plant and animal sources, such as crop residue, composts, green manure, farmyard manure (FYM), and animal and poultry manure, to mention a few, that are utilized as a source of plant nutrients (Thomas *et al.*, 2019; Roba, 2018; Natsheh and Mousa, 2014). Recycling of organic inputs in agroecosystems has been taken as a decisive approach to enhance yields, increase NUE, and minimize environmental pollution posed by the intensive crop-livestock production systems (Wang *et al.*, 2020) (Tables 1 and 2).

Table 1. Influence of organic amendments on crop productivity.

Input type	Crop's response to the organic application	References
Pig manure	Its application enhances grain and straw yield of maize and wheat as compared with NPK fertilization	Wang *et al.*, 2019
Cattle and poultry manure	Their application could significantly improve maize yield over nil control but has no significant differences as compared with an equal amount of chemical fertilizer	Geng *et al.*, 2019
Compost	Its amendments with chemical fertilizer could significantly increase TSW and straw and maize yield over sole chemical fertilization and control	Ejigu *et al.*, 2021
Compost, biochar, and their mixtures	Their amendments with chemical fertilizer could lift the yield of barley by 30 -78% over the control at two different locations in Ethiopia	Agegnehu *et al.*, 2016
Veticompost, Poultry manure, biochar, and poultry tea	Their amendment could increase the pooled maize grain yields by 94.1-261% over the control due to adequate availability of nutrients for plants uptake and improvement in soil physical quality	Are *et al.*, 2018
Compost	It increases maize yield by 21% over the nil control	Laekemariam and Gidago, 2013
Rapeseed, Soybean meal, and cattle manure	Their application potentially enhances maize and wheat yields over the nil control, respectively	Cen *et al.*, 2020

Table 2. Influence of organic fertilization on soil properties.

Input type	Effects on soil properties/quality	References
Pig manure	It increases SOC concentration from 8 to 16 g kg^{-1} and soil pH from 6 to 7	Wang *et al.*, 2019
Compost	Its amendments with chemical fertilizer could increase soil pH, SOC, TN, AP, cation exchange rate (CEC) and, Reduce soil bulk density	Ejigu *et al.*, 2021
Compost, biochar, and their mixtures	Their amendments with chemical fertilizer could increase SOC levels by 23–34%, cation exchange capacity (CEC) by 19-24% and, Lifted soil pH from 5.0 to 5.6 at Holleta and 4.8 to 5.4 at Robgebeya in Ethiopia	Agegnehu *et al.*, 2016
Manure	Increase soil pH (3.3%), SOC (17.7%), TN (15.5%), AN (16%), AP (66.2%), AK (15.5%), Decreased soil bulk density (BD) by 3.9%	Du *et al.*, 2020
Rapeseed, Soybean meal, and cattle manure	Their application enhanced SOM concentration by 54%, 102%, and 88% and TN by 71%, 90%, and 86% over nil control, respectively Moreover, they considerably influence soil microbial community	Cen *et al.*, 2020
Pig manure	Its amendments with chemical fertilizer lifted soil AN, AK, and pH from their initial value by 54%, 180%, and 8%, respectively	Cai *et al.*, 2019

However, the effect of organic inputs on soil and crop productivity may vary depending on several explanatory variables such as rate and type of inputs, input quality, temperature, experimental duration, and soil moisture status, to mention a few. A meta-analysis study conducted in China revealed that the long-term addition of organic manure could significantly enhance grain yield (7.6%) over sole chemical application (Du *et al*., 2020). In the study of Lu (2020) and Chen *et al*. (2018), a lower yield response was revealed at the beginning of the experimental year under organic application, but it gradually showed an increasing trend with experimental duration, emphasizing the potential of organic inputs to enhance crop productivity in the long run. "Turning waste into wealth" is one of the important strategies that encourage the use of organic waste in agriculture. A variety of wastes created by diverse agrarians can create environmental problems by dominating a large space, bad smell, and shelter for the pathogens and source of contamination of groundwater. Therefore, by considering the environmental challenges, the mounting deficiency of plant nutrients in the arable land, and the cost of mineral fertilizers, recycling organic wastes in cropland becomes more important for ensuring sustainable production through soil quality improvement.

Generally, sustainable agricultural production needs appropriate nutrient resources and conservation of soil quality (Roba, 2018). It can supply both macro and micronutrients for plants' uptake. Soil organic carbon (SOC) is a decisive indicator of soil quality due mainly to: improving soil structure, enhancing water retention, enhancing soil nutrient availability through SOM degradation, and increasing the cation exchange capacity (Thomas *et al*., 2019). The adequate availability of SOM increases root growth, and water retention capacity of the soil, promotes soil buffering potential against acidity, and encourages the growth of beneficial microorganisms (Qinglong *et al*., 2020; Natsheh and Mousa, 2014). Despite the positive effects of organic inputs on soil improvement, it has also some drawbacks. It is needed in bulky quantities to fulfill the requisite amount of nutrients for crops due to the low nutrient content in organic inputs (Roba, 2018). It may also comprise a range of heavy metals, potential human pathogens, and persistent organic pollutants that provoke the ecosystem and human health (Urra *et al*., 2019).

Use of enhanced-efficiency fertilizers (EEFs)

Reducing the time that inorganic N is in the soil solution prior to crop uptake can reduce the risk of N losses and increase NUE. Split application (particularly N fertilizer) widely adopted fertilization technique but they increase labor costs and exacerbate N loss. Thus, slow or controlled-release fertilizer (SRF/CRF) has been proposed as a decisive approach to minimize the potential loss and adverse environmental effects induced by conventional urea (Zhu *et al*., 2020). Controlled release N fertilizers are designed to release N into the soil solution at a rate that more closely matches nutrient uptake by the crop, thus helping to avoid wasting of fertilizer, avoid nutrient leaching and prevent pollution of groundwater by fertilizer runoff during flooding. SRF/CRF enhances the efficiency of applied N fertilizers, and they are environment friendly because the N release pattern match with plant N uptake and satisfies plant N demands, and maintains very low amounts of mineral N in soils throughout the plant growth stages (Giday *et al*., 2014). Here, the nutrients can be released in a timely and gradual manner, which attempts to coincide and match with the specific nutrient demand during plant growth (Vejan *et al*., 2021; Lubkowski and Grzmil, 2016).

The CRFs are manufactured by encapsulating or covering fertilizer granules physically with inorganic and/or organic materials with a hydrophobic trait that plays a crucial role as a diffusion wall or barrier. CRF could supply plants with better mineral nutrition for longer periods of duration, ranging from 3 to 18 months with one-time application (Vejan *et al*., 2021). The application of CRU enhances the quality and productivity of crops. The creation of CRFs reduces the loss of nutrients impacted by volatilization and leaching. However, the field applications of SRF/CRF are constrained by the high cost of manufacturing (Vejan *et al*., 2021). The application of 46kg N ha^{-1} of SRU fertilizer had a yield advantage of 462 kg ha^{-1} over the application of 46kg N ha^{-1} of conventional urea (CU) fertilizer in teff (*Eragrostis tef*) in Ethiopia (Giday *et al*., 2014), implying that SRU can reduce N losses. A study revealed that CRU could significantly increase crop yield, N agronomic efficiency, the utilization efficiency of N-fertilizer and N-physiological efficiency by 7.23%, 34.65%, 25.83%, and 15.8%, respectively against the conventional urea (Zhu *et al*., 2020). It also enhanced SOC, TN, and AN by 5.93% and 3.89%, and 13.98%, respectively, as compared with conventional urea in China, but no significant difference was observed in soil pH. The improvement of soil chemical properties due to CRU application may be related to its potential to supply nutrients through increasing crop biomass and its capacity to reduce nutrient loss through runoff, leaching, and volatilization. Overall, slow/controlled release fertilizers release N over several months which could satisfy the N requirement by crops over the whole growing period. Despite their several advantages, their use in field cropsis still limited. For example, the use of CRFs constitutes a mere 1% of the total amount of used fertilizers (Lubkowski and Grzmil, 2016), this is directly related to a higher cost (2-8 times) than conventional fertilizers.

Another category of EEFs is urease and nitrification inhibitors (UI and NI), they are also called N stabilizers. The N stabilizers are designed to slow down the fertilizer (particularly urea) hydrolysis or nitrification rate or both by prolonging the residence time in the soil through the involvement of microorganisms. The most commonly used N stabilizers are N-(n-butyl) thiophosphoric triamide (NBPT) (UI), nitrapyrine (NI) dicyandiamide (DCD) (NI), and 3,4-Dimethylpyrazole phosphate (DMPP) (NI). The effectiveness of these inhibitors is widely assessed in lab and field conditions. Several studies showed the positive response of UI and NI on improving crop productivity and NUE while reducing potential N loss through leaching or gaseous emissions as compared with conventional practices.

Previous study showed that NI application could increase plant N recovery efficiency (58%) and grain productivity (9%) (Qiao *et al*., 2015). However, the efficacy of NIs varies with N management practices, soil texture, pH, crop type, temperature, moisture contents, microbial activity, inhibitor rate, and type. Therefore, for scientific and practical applications, UI/NI characteristics and effects should be taken into consideration.

Use of secondary and micronutrient fertilizers

Despite the groundbreaking efforts since the nineteenth and twentieth centuries, research efforts largely focused on crop productivity and quality, most frequently occurring limiting macronutrients such as N, P, and K. Nevertheless, the essentiality of other mineral nutrients, i.e., magnesium (Mg) has long been disregarded in terms of soil and plant tests and fertilization programs, and its deficiency is not regarded as a substantial concern in agriculture productivity (Ishfaq *et al*., 2022). Production and productivity of many crops are declining due to soil quality deterioration, imbalanced fertilization, inadequate know-how on micro and secondary fertilizers, and so on (Jena *et al*., 2016). Micronutrients are used by plants in relatively small amounts, but they contribute to maximizing crop yield and quality. Secondary elements are as important as primary elements because they help in the uptake of primary elements by plants. They are required in very little quantity as compared to primary elements. Additionally, secondary nutrients such as sulfur, calcium, and magnesium are essential for plant growth and development. The emergence of widespread secondary and micronutrient deficiencies has become a major constraint on productivity (Jena *et al*., 2016). For example, about 55% of arable lands were reportedly magnesium deficient (<120 mg kg^{-1} Ex-Mg) (Ishfaq *et al*., 2022). Farmers give hardly any emphasis on the application of these nutrients. As a result, a decline or stagnation in the production and productivity of many crops is observed, which creates a huge gap between the requirement and supply of food grains (Jena *et al*., 2016). Secondary nutrient deficiencies prevent plants from utilizing primary nutrients to their fullest extent, which ultimately stunts growth.

A balanced supply of NPK and secondary/micronutrients is critical for the improvement of crop growth and yield, and hence, a higher NUE can be achieved (Ding *et al*., 2018). The study showed that the application of secondary/micronutrient fertilizers (SMF) significantly increased rice yield by 4.6% relative to the control (fertilized without secondary or micronutrients), with the highest rice yield response with boron supply (8.1%) and lowest with sulfur (1.9%) (Ding *et al*., 2018). A meta-analysis study revealed that the application of magnesium fertilizer could lift crop yield by 8.5% regardless of the crop type, soil condition, and other factors (Wang *et al*., 2020). Therefore, it is crucial to promote the use of secondary nutrients and micronutrients, particularly in field crops to enhance crop productivity.

Conclusion

Optimization of nutrient use in field crops through adopting different fertilization management options is crucial to improve grain yield and FUE while reducing adverse environmental effects. In the present review, three AFOs were reviewed and their potential effects on crops, soil, and FUE were elucidated. Organic amendments can potentially enhance soil fertility and then enhance crop productivity. The use of EEFs potentially reduces N-loss through ammonification and leaching, thereby enhancing crop yield and fertilizer efficiency. Despite the use of secondary nutrients not widely adopted globally due to major attention given to primary macronutrients (N, P, and K), they play a significant role in crop production. It also enhances the nutrient uptake of primary nutrients. In summary, the adoption of AFOs can enhance yield and NUE and helps to achieve sustainable production. This study only highlighted three AFOs and further research is needed to fully examine its overall effectiveness, taking into account various explanatory factors. and also studying the remaining AFOs is an important task in the future.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Agegnehu, G., Nelsona, P., & Michael, B. (2016). Crop yield, plant nutrient uptake and soil physicochemical properties under organic soil amendments and nitrogen fertilization on Nitisols. *Soil & Tillage Research*, *160*, 1–13, https://doi.org/10.1016/j.still.2016.02.003

Are, K. S., Adelana, A. O., Fademi, O., & Abel, O. (2018). Improving physical properties of degraded soil: Potential of poultry manure and biochar. *Agriculture and Natural Resources*, *51*, 454–462, https://doi.org/10.1016/j.anres.2018.03.009

Cai, A., Xu, M., Wang, B., Zhang, W., Liang, G., & Hou, E. (2019). Manure acts as a better fertilizer for increasing crop yields than synthetic fertilizer does by improving soil fertility. *Soil & Tillage Research*, *189*, 168–175, https://doi.org/10.1016/j.still.2018.12.022

Cen, Y., Guo, L., Liu, M., Gu, X., & Li, C. (2020). Using organic fertilizers to increase crop yield, economic growth, and soil quality in a temperate farmland. *PeerJ*. https://doi.org/10.7717/peerj.9668

Chen, Y., Camps-Arbestain, M., Shen, Q., Singh, B., & Cayuela, M. L. (2018). The long-term role of organic amendments in building soil nutrient fertility: a meta-analysis and review. *Nutrient Cycling in Agroecosystems*, *111*, 103–125, https://doi.org/10.1007/s10705-017-9903-5

Chianu, J., Chianu, J., & Mairura, F. (2012). Mineral fertilizers in the farming systems of sub-Saharan Africa. A review. *Agronomy for Sustainable Development*, *32*, 545–566, https://doi.org/10.1007/s13593-011-0050-0

Dhillon, J. S., Eickhoff, E. M., Mullen, R. W., & Raun, W. R. (2019). World potassium use efficiency in cereal crops. *Agronomy Journal*, *111*(2), https://doi.org/10.2134/agronj2018.07.0462

Dhillon, J., Torres, G., Driver, E., Figueiredo, B., & Raun, W. R. (2017). World phosphorus use efficiency in cereal crops. *Agronomy Journal*, *109*(4), 1670–1677, https://doi.org/10.2134/agronj2016.08.0483

Ding, W., Xu, X., He, P., Ullah, S., Zhang, J., Cui, Z., & Zhou, W. (2018). Improving yield and nitrogen use efficiency through alternative fertilization options for rice in China: A meta-analysis. *Field Crops Research*, *227*, 11–18, https://doi.org/10.1016/j.fcr.2018.08.001

Du, Y., Cui, B., Zhang, Q., Wang, Z., Sun, J., & Niu, W. (2020). Effects of manure fertilizer on crop yield and soil properties in China: A meta-analysis. *Catena*, *193*. https://doi.org/10.1016/j.catena.2020.104617

Ejigu, W., G.Selassie, Y., Elias, E., & Damte, M. (2021). Integrated fertilizer application improves soil properties and maize (*Zea mays* L.) yield on Nitisols in Northwestern Ethiopia. *Heliyon*, *7*(2), e06074. https://doi.org/10.1016/j.heliyon.2021.e06074

Geng, Y., Cao, G., Wang, L., & Wang, S. (2019). Effects of equal chemical fertilizer substitutions with organic manure on yield, dry matter, and nitrogen uptake of spring maize and soil nitrogen distribution. *PLoS ONE*, *14*(7). https://doi.org/10.1371/journal.pone.0219512

Giday, O., Gibrekidan, H., & Berhe, T. (2014). Response of teff (Eragrostis tef) to different rates of slow release and conventional urea fertilizers in vertisols of southern Tigray, Ethiopia. *Advances in Plants & Agriculture Research*, *1*(5), 190–197, https://doi.org/10.15406/apar.2014.01.00030

Heffer, P., Armelle, G., & Terry, R. (2017). *Assessment of fertilizer use by crop at the global level.* (Issue International Fertilizer Industry Association).

Ishfaq, M., Wang, Y., Yan, M., Wang, Z., Wu, L., Li, C., & Li, X. (2022). Physiological Essence of Magnesium in Plants and Its Widespread Deficiency in the Farming System of China. *Frontiers in Plant Science*, *13*, 1–17, https://doi.org/10.3389/fpls.2022.802274

Jena, B., Nayak, R. K., Das, J., Parida, R. K., & Sethi, D. (2016). Secondary and Micro Nutrient mapping in forest soils of Kandhamal district, Odisha. *Agropedology*, *26*(01), 79–86, https://doi.org/10.47114/j.agroped.2016.jun10

Laekemariam, F., & Gidago, G. (2013). Growth and yield performance of Maize (Zea mays L.) to Variable rates of compost and Inorganic Fertilizer Integration in Wolaita, Southern Ethiopia. *American Journal of Plant Nutrition and Fertilization Technology*, *3*(2).

Legesse, E.-E., Srivastava, A.-K., Kuhn, A., & Gaiser, T. (2019). Household Welfare Implications of Better Fertilizer Access and Lower Use Inefficiency: Long-Term Scenarios for Ethiopia. *Sustainability*, *11*. https://doi.org/doi:10.3390/su11143952

Liu, X., Vitousek, P., Chang, Y., Zhang, W., Matson, P., & Zhang, F. (2016). Evidence for a Historic Change Occurring in China. *Environmental Science and Technology*, *50*(2), 505–506, https://doi.org/10.1021/acs.est.5b05972

Lu, X. (2020). A meta-analysis of the effects of crop residue return on crop yields and water use efficiency. *PLoS ONE*, 1–18, https://doi.org/10.1371/journal.pone.0231740

Lubkowski, K., & Grzmil, B. (2016). Controlled release fertilizers. *Polish Journal of Chemical Technology*, *9*(4), 81–84, https://doi.org/10.2478/v10026-007-0096-6

Natsheh, B., & Mousa, S. (2014). Effect of Organic and Inorganic Fertilizers Application on Soil and Cucumber (*Cucumis Sativa* L.) Plant Productivity. *International Journal of Agriculture and Forestry*, *4*(3), 166–170, https://doi.org/10.5923/j.ijaf.20140403.03

Qinglong, Y., Fengxia, Z., Xucun, J., Peng, L., Shuting, D., Jiwang, Z., & Bin, Z. (2020). The combined application of organic and inorganic fertilizers increases soil organic matter and improves soil microenvironment in wheat-maize field. *Journal of Soils and Sediments*, *20*, 2395–2404.

Qiao, C., Liu, L., Hu, S., Compton, J. E., Greaver, T. L., & Li, Q. (2015). How inhibiting nitrification affects nitrogen cycle and reduces environmental impacts of anthropogenic nitrogen input. *Global Change Biology*, *21*(3), 1249-1257, https://doi.org/10.1111/gcb.12802

Roba, T. B. (2018). The Effect of Mixing Organic and Inorganic Fertilizer on Productivity and Soil Fertility. *Open Access Library Journal*, *5*. https://doi.org/10.4236/oalib.1104618

Sharma, L. K., & Bali, S. K. (2018). A review of methods to improve nitrogen use efficiency in agriculture. *Sustainability*, *10*. https://doi.org/10.3390/su10010051

Thomas, C. L., Acquah, G. E., Whitmore, A. P., Mcgrath, S. P., & Haefele, S. M. (2019). The Effect of Different Organic Fertilizers on Yield and Soil and Crop Nutrient Concentrations. *Agronomy*, *9*. https://doi.org/10.3390/agronomy9120776

Urra, J., Alkorta, I., & Garbisu, C. (2019). Potential benefits and risks for soil health derived from the use of organic amendments in agriculture. *Agronomy*, *9*. https://doi.org/10.3390/agronomy9090542

Van Beek, C. L., Elias, E., Yihenew, G. S., Heesmans, H., Tsegaye, A., Feyisa, H., Tolla, M., Melmuye, M., Gebremeskel, Y., & Mengist, S. (2016). Soil nutrient balances under diverse agro-ecological settings in Ethiopia. *Nutrient Cycling in Agroecosystems*, *106*, 257–274, https://doi.org/10.1007/s10705-016-9803-0

Vejan, P., Khadiran, T., Abdullah, R., & Ahmad, N. (2021). Controlled release fertilizer: A review on developments, applications and potential in agriculture. *Journal of Controlled Release*, *339*, 321–334, https://doi.org/10.1016/j.jconrel.2021.10.003

Vitousek, P. M., Katzenberger, J., Martinelli, L. A., Matson, P. A., Nziguheba, G., Ojima, D., Palm, C. A., Robertson, G. P., Sanchez, P., Townsend, A. R., & S, Z. F. (2009). Nutrient Imbalances in Agricultural Development. *Science*, *324*, 1519–1520.

Wang, H., Xu, J., Liu, X., Zhang, D., Li, L., Li, W., & Sheng, L. (2019). Effects of long-term application of organic fertilizer on improving organic matter content and retarding acidity in red soil from China. *Soil & Tillage Research*, *195*. https://doi.org/10.1016/j.still.2019.104382

Wang, X., Yang, Y., Zhao, J., Nie, J., Zang, H., & Zeng, Z. (2020). Yield benefits from replacing chemical fertilizers with manure under water deficient conditions of the winter wheat–summer maize system in the North China Plain. *European Journal of Agronomy*, *119*, 126118. https://doi.org/10.1016/j.eja.2020.126118

Wang Z, Hassan MU, Nadeem F, Wu L, Zhang F and Li X (2020) Magnesium Fertilization Improves Crop Yield in Most Production Systems: A Meta-Analysis. *Frontiers in Plant Science*, 10:1727. https://doi.org/10.3389/fpls.2019.01727

World Bank. (2021). *World Development Indicators. Fertilizer consumption [kg per hectare of arable land]. Retrieved from https://data.worldbank.org/indicator/AG.CON.FERT.ZS.*

Yokamo, S., Xiaoqiang, J., Gurmu, F., Tettey, C. K., & Jiang, R. (2022). Cereal production trends, nutrient use efficiency and its management practices in agriculture: A review. *Archives of Agriculture and Environmental Science*, *7* (1), 114–120.

Zhang, W., Wang, Q., Wu, Q., Zhang, S., Zhu, P., Peng, C., Huang, S., Wang, B., & Zhang, H. (2020). The response of soil Olsen-P to the P budgets of three typical cropland soil types under long-term fertilization. *PLoS ONE*, *15*(3), 1–17, https://doi.org/10.1371/journal.pone.0230178

Zhang, Xiaoying, Fang, Q., Zhang, T., Ma, W., Velthof, G. L., Yong, H., Oene, O., & Fusuo, Z. (2020). Benefits and trade-offs of replacing synthetic fertilizers by animal manures in crop production in China: A meta-analysis. *Global Change Biology*, *26*, 888–900, https://doi.org/10.1111/gcb.14826

Zhang, Xin, Davidson, E., Mauzerall, D. L., Searchinger, T., Dumas, P., & Shen, Y. (2015). Managing nitrogen for sustainable development. *Nature*. https://doi.org/10.1038/nature15743

Zhu, S., Liu, L., Xu, Y., Yang, Y., & Shi, R. (2020). Application of controlled release urea improved grain yield and nitrogen use efficiency: A meta-analysis. *PLoS ONE*, *15*(10). https://doi.org/10.1371/journal.pone.0241481