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Combined application of chemical fertilizer and enriched household vermicompost influences maize yield and soil quality under calcareous soil

Rajesh Kumar, Shankar Jha, Shiveshwar Pratap Singh, Mukesh Kumar, Niru Kumari and Rajeev Padbhushan

Rajesh Kumar
Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, Bihar Agricultural University, Sabour Bhagalpur, Bihar, India

Sankar Jha
Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India

Shiveshwar Pratap Singh
Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India

Mukesh Kumar
Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India

Niru Kumari
Bihar Agricultural University, Sabour Bhagalpur, Bihar, India

Rajeev Padbhushan
Bihar Agricultural University, Sabour Bhagalpur, Bihar, India

Corresponding Author:
Rajesh Kumar
Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, Bihar Agricultural University, Sabour Bhagalpur, Bihar, India

Abstract
Intensive cultivation and imbalance fertilization have declined the quality of soil and maize yield in calcareous soil. In order to obtain good crop yield, proper soil management is important. In preview of this the present study was designed with treatments combinations including chemical fertilizers, household vermicompost, rock phosphate addition and zinc (Zn) over the control (no fertilizer). Use of integrated rock phosphate and Zn in the vermicompost along with chemical fertilizer resulted in higher crop yield than vermicompost added with rock phosphate and Zn alone along with chemical fertilizers which were *at par* with full recommended dose of chemical fertilizer (RDF). Also, soil parameters were improved on combining rock phosphate and Zn in the vermicompost along with chemical fertilizers than RDF and control. Therefore, combined use of household vermicompost enriched with rock phosphate and Zn can be best substituted for 25% N using chemical fertilizer and increased grain yield and soil organic carbon (SOC) higher by 8.0% and 7.5% than RDF. Overall, this study concluded that integrated use of chemical fertilizer along with household waste enriched vermicompost improved the crop yield and soil sustainability in calcareous soil.

Keywords: organic manure, rock phosphate, zinc sulphate, maize yield, soil sustainability

Introduction
Maize (*Zea mays* L.) is a food and fodder crop grown under diverse soils and consumed all over the world after rice and wheat. High yield potential and better adaptability to diverse situations than the other cereal crops have increased its popularity among growers (Kumar *et al.*, 2022) [27]. Also, nutritional value of this crop has augmented its importance for consuming. India is one of the world's foremost producers of maize, producing 27.2 million tonnes on an area of about 9.75 million hectares; however this crop only yields an average of 2.8 tonnes per hectare. In India, Bihar state is one of the major maize growers with highest productivity and grown in all round year (Kharif/Rabi/Zaid/summer). The total area of 0.72 million hectares is covered by this crop with total production 3.8 million tonnes and productivity 5.3 tonnes per hectare (Anonymous, 2017) [5]. The data shows the state potential of production but an important issue is associated with the productivity of this crop in the state i.e. soil quality. Maize is one of the largest nutrient mining crops from the soil system. Therefore, maintenance of high productivity requires proper management of soil nutrient balance which is a real concern for today.

Nutrient management means use of balanced nutrients based on soil and crop requirement (Kumari *et al.*, 2021) [28]. At the time of application of fertilizers, we do not keep these factors into consideration. This resulted in low productivity of the crop and poor soil quality. In many areas of the country, the improper and imbalanced use of fertilisers has resulted in widespread nutrient deficiency and soil degradation (Padbhushan *et al.*, 2015a) [36]. Currently, the soils of India are facing the deficiencies of macronutrients as well as micronutrients (Padbhushan *et al.*, 2015b) [37]. Therefore, maintaining increased soil and crop yield requires adequate fertiliser management (Sharma *et al.*, 2019) [38].

Studies shows that integrated nutrient management can be a good option for managing soil heath and crop productivity wherein chemical fertilizers are integrated with organic sources of nutrient (Sharma *et al.*, 2019; Padbhushan *et al.*, 2021) [38, 41]. Some of the long-term studies have also signified the importance of organic amendments on soil fertility and crop yield (Padbhushan *et al.*, 2016a; Padbhushan *et al.*, 2016b) [39, 40].

An application of organic manures increases the effectiveness of fertiliser usage and maintains health of the soil system for long-term sustainability. Organic sources such as farmyard manure (FYM), vermicompost and biofertilizers can be used to integrate with chemical fertilizers (Padbhushan *et al.*, 2015c) [38]. Different substrates such as municipal wastes and household wastes can be utilized for vermicompost preparation and its quality can be improved by several enrichment techniques.

Comparing crop produces, nitrogen (N) use efficiency, and the availability of nutrients in the soil, enriched vermicompost was utilised to replace inorganic N fertiliser. The use of enriched vermicompost manure for nutrient control in sustainable agricultural intensification has gained popularity recently. Enrichment of vermicompost is done using rock phosphate which contains 18-20% of the phosphorus (P) (Akande *et al.*, 2005) [2]. Rock phosphate is a cheaper fertilizer than commercial fertilisers, but plants cannot absorb this P alone due to insolubility in water (Sarwar *et al.*, 2008) [44]. Use of organic composts like vermicompost, FYM and chicken manure is particularly effective with rock phosphate for increasing its availability (Billah *et al.*, 2022) [17].

Several techniques are employed to forecast changes in the soil quality. The physical, chemical, biological and characteristics of soils can be used as markers of its value (Abbott and Murphy, 2003) [1]. Soil acidification (Guo *et al.*, 2010) [21], eutrophication (Zhang *et al.*, 2011) [55], greenhouse gases emission, N deposition, excessive application of N and calcium carbonate deposition (calcareous soil) causes environmental contamination (Padbhushan *et al.*, 2014) [35]. Therefore, ensuring food security in the regions while lowering environmental costs is a significant problem.

The present study hypothesized that household waste based vermicompost added with rock phosphate can be good source of organic amendment and can be integrated with chemical fertilizers to apply in the calcareous soil. The aims of this study are 1). To see the impact of integrated use of chemical fertilizers and enriched household vermicompost on maize crop in calcareous soil and 2). To determine the soil quality on combining use of inorganic fertilizers and enriched household vermicompost in calcareous soil.

Materials and Methods

Location area

This study was led to evaluate the various forms of vermicompost made at RPCAU, Pusa, Samastipur, using household wastes with or without enhanced rock phosphate (Bihar). The site's coordinates were 25° 58' 12" N, 85° 41' 24" E, and it was 55 metres above sea level. Climate is subtropics sub humid with sandy loam textured calcareous soil.

Substrate for experimentation

Organic residues and household garbage were the different organic components used to make vermicompost. Rice straw, an organic residue, was taken from the RPCAU research farm in Pusa, Samastipur. Before being used to prepare vermicompost, the collected household garbage from the university housing complexes was inspected for plastic bags, polythene bags, and other undesired elements. All of these waste products were then processed for the creation of vermicompost after being sun-dried for a couple of days in the shade. The enrichment of vermicompost was done using rock phosphate which contains P_2O_5 from 18 to 20%

Crop and nutrient management

Maize crop was grown for two years in the calcareous soil using RHM-4 variety suitable for this climate and soil. Randomized block design (RBD) using six treatments and replication thrice was done in the maize field. Recommended spacing (60 x 20 cm) was also followed while sowing of crop in a raised bed method. Nutrient management was done using recommended dose of fertilizer (RDF) for maize (120:60:40 N: P: K kg ha^{-1}). The sources of fertilizers were urea (N), diammonium phosphate (N and P) and muriate of potash (K). Additionally, enriched vermicompost was employed in place of inorganic fertilisers. Fertilization was at the critical stages of the crop (vegetative, knee-high and tasselling) in the presence of assured irrigation facility. The amount of fertilizers in the different stages were applied as 50% of N in the basal along with full doses of P and K, other 50% of N with one-half during knee-stage and left half at tasselling stage of the crop. Intercultural operations were done to remove weed manually and diseases/pests were monitored regularly and management were done properly.

Treatment detail

The treatment combinations used for this research were 1). T_1-Absolute Control; 2). T_2- RDF; 3). T_3-75% nitrogen using chemical fertilizer + 25% nitrogen using household based vermicompost; 4). T_4-75% nitrogen using chemical fertilizer + 25% nitrogen using household based vermicompost enriched with rock phosphate; 5). T_5-75% nitrogen using chemical fertilizer + 25% nitrogen using household based vermicompost enriched with $ZnSO_4$ @ 25 kg ha^{-1}; 6). T_6-75% nitrogen using chemical fertilizer+25% nitrogen using household based vermicompost enriched with rock phosphate and $ZnSO_4$ @ 25 kg ha^{-1}. The treatments were laid in RBD and replicated thrice.

Crop harvest and soil analysis

Maize crop was harvested at maturity from individual treatments and yield was determined using grain, stover and stone of the crop. Initial soil of the experimentation was collected. Soil parameters studied were sandy loam textured, pH-8.45 (1:2), EC-0.56 dSm^{-1}, N-155 kg ha^{-1}, P-20.28 kg ha^{-1}, K-125.2 kg ha^{-1}, Free $CaCO_3$ (%)-24.68 and SOC-6.5 g kg^{-1}. Following crop harvest, soil samples from each treatment were taken and examined for various soil characteristics. The soil analysis protocol used the EC and pH proposed by Jackson (1973) [22], the soil organic carbon determined by the Walkley and Black method (1934) [56], the available N determined by the Subaiah and Asija method (1956) [50], the available P determined by the bicarbonate method (Olsen *et al*., 1954) [34], and the available K determined by the ammonium acetate method (Jackson, 1973) [22]. Zn, Cu, Mn, and Fe available micronutrients were studied using the Lindsay and Norvell approach (1978) [30].

Statistical Analysis

Data for various parameters was analysed using ANOVA for variance through Duncan Multiple Range Test (DMRT) considering the treatments represented through least significance difference at 5% and presented as table/graph.

Results and Discussion

Maize yield

Grain, stover and stone yield of maize crop was increased by the fertilization compared to control (T_1, no fertilizer) as shown in the Figure 1. Use of integrated rock phosphate and Zn in the vermicompost along with chemical fertilizer (T_6) resulted in better crop yield than vermicompost applied with or without rock phosphate (T_3 & T_5) and with or without Zn alone (T_3, T_4 & T_5) along with chemical fertilizer which were *at par* with RDF. Therefore, combined use of household vermicompost enriched with rock phosphate and Zn could be best substituted for 25% N chemical fertilizer and increased grain yield higher by 8% than full dose of recommended fertilizer. The increased in grain yield in the treatment T_6 shows the role of organic manure and Zn on crop growth and development in reproductive phase. The release of essential nutrients during mineralization is being utilized for proper photosynthetic phenomenon resulted in enhanced plant growth and grain setting in maize crop. Similar results are in congruent with (Nath and Singh, 2012) [33] who found that use of compost as organic amendment led to high grain yield of maize. The rise in stover yield in organic sources substituted with inorganic fertilizer was result to the association to better environment amelioration and more supply of nutrients. The result was similar to the results of the Singh *et al.* (2014) and Kumar *et al.* (2014) [49, 26]. Similarly, higher stone yield was due to the ability of enriched household vermicompost to suppress plant pest/pathogen that contributes to maize growth.

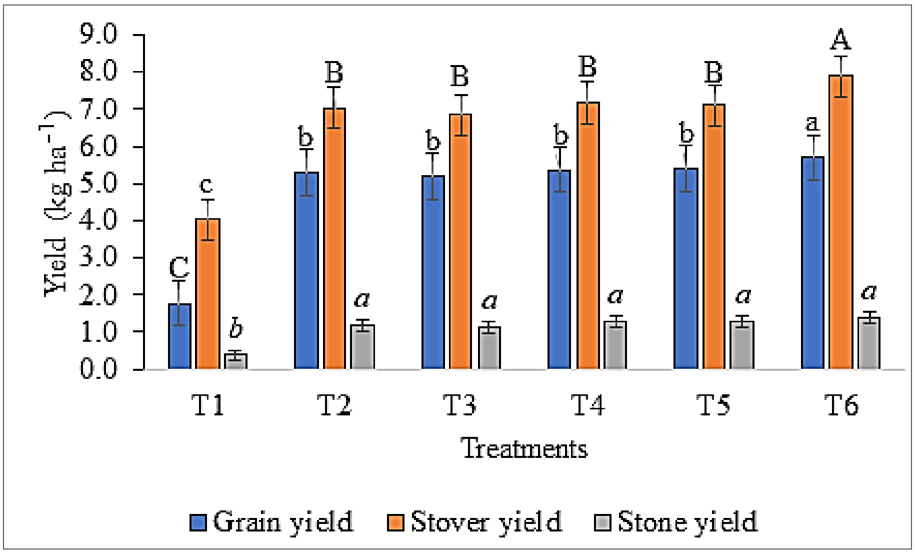

Fig 1: Effect of treatments on yield of maize crop (grain, stover and stone) in the calcareous soil after harvest of maize crop (T1-Absolute Control; T2- RDF; T3-75% nitrogen using chemical fertilizer + 25% nitrogen using household based vermicompost; T4-75% nitrogen using chemical fertilizer + 25% nitrogen using household based vermicompost enriched with rock phosphate; T5-75% nitrogen using chemical fertilizer +25% nitrogen using household based vermicompost enriched with $ZnSO_4$ @ 25 kg ha^{-1}; T6-75% nitrogen using chemical fertilizer +25% nitrogen using household based vermicompost enriched with rock phosphate and $ZnSO_4$ @ 25 kg ha^{-1}; Data presented through DMRT in which similar letters are showing statistically non-significant)

Soil physico-chemical properties

Overall pH was alkali in nature. Soil pH was significantly declined on fertilization except RDF compared to control (Figure 2). The rock phosphate addition and use of Zn changed the soil pH relative to RDF as reported by Ali *et al.* (2014) [4]. The application of rock phosphate decreased the soil pH because of more release and mineralization of H^+ ions during rock phosphate dissolution process (Li, J., and P. Marschner, 2019) [29]. When rock phosphate was added in conjunction with the application of chemical fertilisers and organic amendments, Ain (2018) [3] also discovered a decrease in soil pH following the harvest of maize and sorghum. The application of vermicompost decreased soil pH and enhanced microbial activity, which impacted the availability of nutrients to plant, roots (Atiyeh *et al.*, 2001) [8].

Electrical conductivity was also significantly declined on use of vermicompost and rock phosphate addition over the control but they were *at par* RDF treatment (Figure 2). Sharif *et al.* (2014) [46] had seen decline in EC using vermicompost as source of nutrients. The increased concentration of salts due to vermicompost and rock phosphate resulted in lowered EC than RDF and control.

The use of vermicompost and rock phosphate addition improved the SOC content relative to control and RDF (Figure 2). The amount of SOC was increased by 7.5% in the best treatment T_6 which is applied with the combination of chemical fertilizer, enriched vermicompost and Zn relative to the treatment T_2 which is supplied with chemical fertilizer alone (Figure 2). Because of superior growth and higher average yields, the addition of vermicompost and rock phosphate increased the turnover of the root biomass, which improved the SOC content of the soil. Our finding was corroborated with finding of Kannan *et al.* (2013) and Basak *et al.* (2020) [24, 10]. SOC is one of the important soil quality indicators. Improvement in its content can improve the quality of soil as well as soil nutrients status.

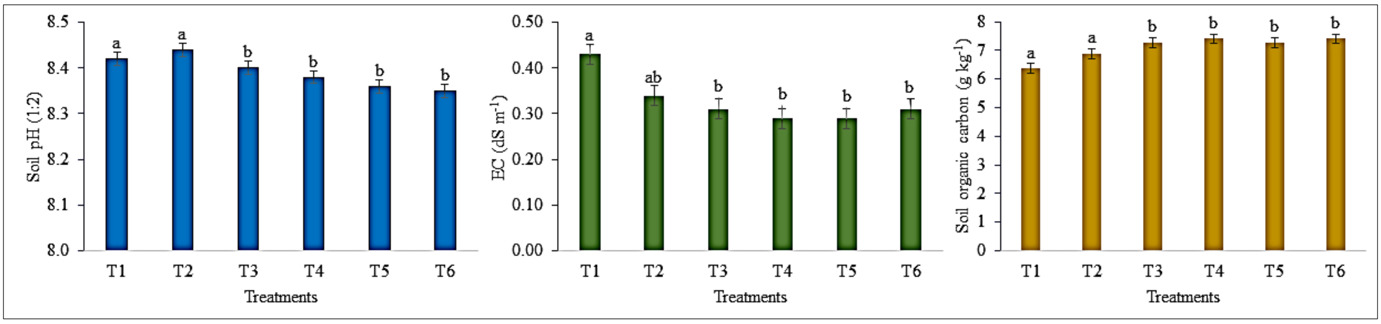

Fig 2: Effect of treatments on soil pH, EC and soil organic carbon in the calcareous soil after harvest of maize crop (T1-Absolute Control; T2-RDF; T3-75% nitrogen using chemical fertilizer + 25% nitrogen using household based vermicompost; T4-75% nitrogen using chemical fertilizer + 25% nitrogen using household based vermicompost enriched with rock phosphate; T5-75% nitrogen using chemical fertilizer +25% nitrogen using household based vermicompost enriched with $ZnSO_4$ @ 25 kg ha^{-1}; T6-75% nitrogen using chemical fertilizer +25% nitrogen using household based vermicompost enriched with rock phosphate and $ZnSO_4$ @ 25 kg ha^{-1}; Data presented through DMRT in which similar letters are showing statistically non-significant)

Soil available macronutrients

Use of vermicompost and rock phosphate addition improved soil available N and K over the control but it was statistically *at par* RDF (Figure 3). However, enrichment with rock phosphate improved significantly the available P content in the treatments T_4 and T_6 compared to treatments T_2, T_3 and T_5. Application of inorganic nutrients and organic soil amendments has improved the soil's macronutrient content. The use of organic materials contributes to a larger proliferation of soil microorganisms that transform nutrients that are bonded to organic matter into inorganic forms of nutrients. (Arancon and Edwards, 2005) [7]. Basak *et al.* (2012) [11] showed that integrated application of chemical fertilizers and vermicompost under maize–wheat cropping increased mineral nutrients in the soil. Due to the production of organic acids during the breakdown of fresh organic matter, such as citric acid, lactic acid, acetic acid, butyric acid, and chelating substances, which aid in the solubilization of P from low-grade rock phosphate, the availability of P from rock phosphate enriched vermicompost is higher (Biswas and Narayanasamy, 2006; Biswas *et al.*, 2009) [12, 13]. Use of Zn in combination with rock phosphate in the household vermicompost improved the nutrients availability in the soil. Excessive nutrients loss was observed in the treatment where no fertilizer application was done (Figure 3). According to Gaffar *et al.* (1992) and Yashpal *et al.* (1993) [20, 54], adding organic matter to calcareous soil increased the availability of phosphate because CO_2 generation dominates P availability.

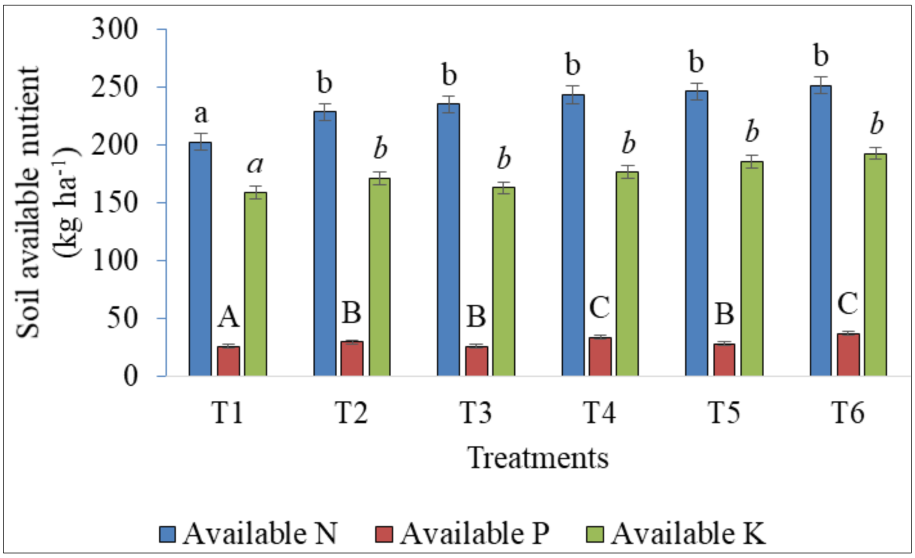

Fig 3: Effect of treatments on soil available macronutrients (N, P and K) in the calcareous soil after harvest of maize crop (T1-Absolute Control; T2- RDF; T3-75% nitrogen using chemical fertilizer + 25% nitrogen using household based vermicompost; T4-75% nitrogen using chemical fertilizer + 25% nitrogen using household based vermicompost enriched with rock phosphate; T5-75% nitrogen using chemical fertilizer+ 25% nitrogen using household based vermicompost enriched with $ZnSO_4$ @ 25 kg ha^{-1}; T6-75% nitrogen using chemical fertilizer+25% nitrogen using household based vermicompost enriched with rock phosphate and $ZnSO_4$ @ 25 kg ha^{-1}; Data presented through DMRT in which similar letters are showing statistically non-significant)

Soil available micronutrients

Similar to macronutrients, rock phosphate addition and zinc use in the vermicompost improved the available Zn and Fe content in the soils, however no change was found in the available Cu and Mn (Figure 4). The treatment T_6 has significantly highest soil available Zn followed by T_5 over the T_1. Treatments T_2, T_3 and T_4 had *at par* soil available Zn with T_1. Soil available Fe was increased on application of rock phosphate and Zn. The highest Fe content was found in the T_6 which is *at par* with T_4 and T_5. The lowest Fe content was found in the treatment T_1, is *at par* with T_2 and T_3 (Figure 4). The improvement in these nutrients in the soil is due to loading of rock phosphate and Zn in the treatments. According to Sarkar *et al.* (1996) [57], the application of organic fertilisers increased the amount of accessible Zn in calcareous soil.

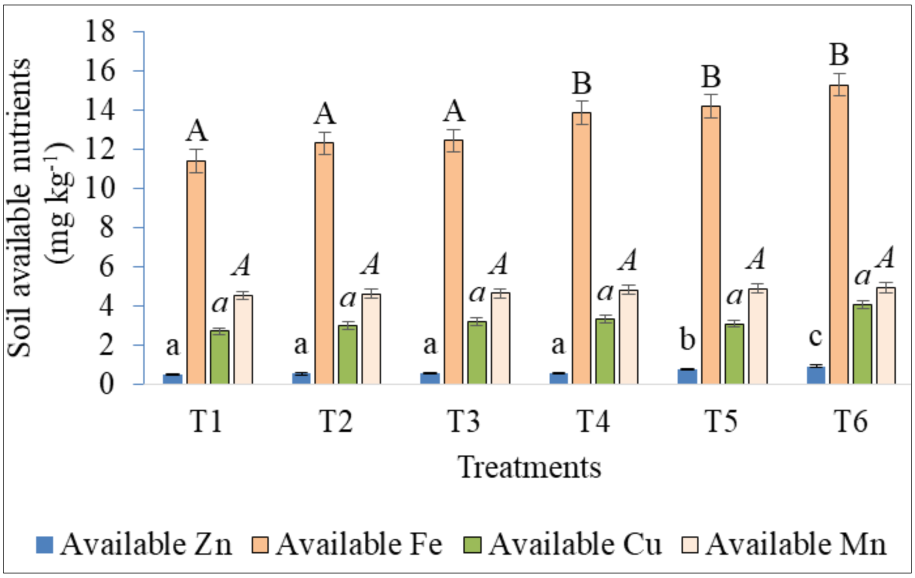

Fig 4: Effect of treatments on soil available micronutrients (Zn, Fe, Cu and Mn) in the calcareous soil after harvest of maize crop (T1-Absolute Control; T2- RDF; T3-75% nitrogen using chemical fertilizer + 25% nitrogen using household based vermicompost; T4-75% nitrogen using chemical fertilizer + 25% nitrogen using household based vermicompost enriched with rock phosphate; T5-75% nitrogen using chemical fertilizer + 25% nitrogen using household based vermicompost enriched with $ZnSO_4$ @ 25 kg ha^{-1}; T6-75% nitrogen using chemical fertilizer + 25% nitrogen using household based vermicompost enriched with rock phosphate and $ZnSO_4$ @ 25 kg ha^{-1}; Data presented through DMRT in which similar letters are showing statistically non-significant)

Conclusion

This study concluded that enrichment techniques to vermicompost with rock phosphate and zinc improved the maize yield and soil parameters in the calcareous soil. Nutrient mining can be minimized either applying balanced fertilizers or integrating chemical fertilizers with organic sources. Use of enrichment techniques dissolute the rock phosphate and enhance its availability in soil and plant uptake resulted in better crop growth. 25% of chemical N fertilizer can be substituted with vermicompost for maintaining crop yield and soil sustainability.

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