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Sustaining Soil Fertility: Exploring the Long-Term Effects of Chemical Fertilizers and Farmyard Manure Application

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Long-term fertilizer and manure experiments serve as invaluable resources for investigating various aspects of agriculture and soil management. These experiments provide a wealth of information on yield trends, nutrient dynamics, and soil nutrient balances. They also help in predicting a soil's carrying capacity, assessing soil quality, and evaluating the sustainability of agricultural systems. Long-term fertilizer experiments play a crucial role in separating the complex interactions among soils, plants, climate, and management practices and shedding light on their impacts on crop productivity. Long-term fertilizer experiments were initiated in the early 1970s, and they have been periodically evaluated since then. The continuous, long-term use of chemical fertilizers and manures is highly influencing the chemical nature and fertility status of the soil.

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1. INTRODUCTION

Sustaining soil health is crucial for meeting three fundamental human necessities, i.e., food, fibre, and shelter. Beyond these essential requirements, soil serves a multitude of vital functions. It acts as a universal filter, purifying water and air while also serving as a reservoir for water and nutrients essential for plant growth. Soil is a habitat for beneficial soil organisms, provides physical support to plants, moderates the climate, and helps to maintain ecological balance by regulating atmospheric gases.

Soil plays a key role in providing the nutrients necessary for the sustained growth of crops, including vital elements like nitrogen, phosphorus, potassium, and trace elements. Soil fertility, which reflects a combination of plant growth and its ability to interact with nutrient and environmental conditions, is fundamental for achieving consistent, high, and sustainable crop yields. Fertilisation is a well-established method for enhancing soil fertility and boosting crop production [1]. The continual application of fertiliser nutrients has contributed to steady increases in crop yields, ensuring a consistent food supply. However, it's essential to note that improper fertilisation practices can lead to deteriorating soil quality, reduced crop yield and quality, and various environmental issues, such as greenhouse gas emissions and agricultural non-point source pollution. Consequently, employing scientific and well-balanced fertilisation techniques is crucial for preserving soil fertility and ensuring stable crop yields. For instance, recent research has established that judicious fertilisation not only enhances soil fertility and farm productivity but also reduces fertiliser requirements, enhances fertiliser efficiency, and mitigates environmental risks. The long-term fertiliser experiments conducted in India over many years have proven invaluable for assessing and quantifying the impact of continuous cropping and fertiliser application on soil quality. These experiments play a vital role in assessing the sustainability of agricultural systems. Long-term trials serve as a healthy basis for evaluating sustainable agricultural management practices by capturing past data and potentially acting as an early care system for future challenges.

2. EFFECT OF CHEMICAL FERTILIZER AND ORGANIC MANURE ON SOIL PH AND ELECTRICAL CONDUCTIVITY

Soil physico-chemical parameters, notably soil pH and electrical conductivity (EC), exert profound influences on the solubility of nutrients within the soil matrix. These parameters are the outcome of multi-layered processes, often driven by the activities of soil biota. Their primary significance lies in their key roles in modifying the osmotic equilibrium of plants, directly influencing the uptake of water and essential nutrients. The chemical fertility of soil emerges as an intermediary between overall soil health and the sustainability of agricultural crops. It serves as a reliable metric for assessing the availability of vital nutrients for plants. The chemical attributes of soil mirror its capacity to provide an amenable chemical and nutritional environment for plant growth.

An experiment on Vertisols at Jabalpur found that the addition of FYM along with inorganic nutrients slightly reduced the soil pH. The change was marginal and non-significant, which was attributed to the higher buffering capacity of vertisols. The high buffering capacity of the soil on the one hand and the presence of an appreciable amount of free calcium carbonate on the other hand neutralise the H+ forms in the mineralization of nitrogenous fertiliser [2]. In addition to fertiliser-induced changes, the introduction of organic matter was observed to release organic acids that could also affect soil pH, indicating the impact of organic matter on soil pH levels through the release of organic acids. Similar findings were observed by the authors [3,4].

The application of integrated nutrients did not result in a significant impact on the electrical conductivity (EC) of the soil. Typically, inorganic fertilisers contain residual salts, and their prolonged use over an extended period is expected to influence the EC of the soil. However, in this study, it was observed that the values of EC remained relatively stable and did not exhibit remarkable changes. The applied inputs had a low residual effect on the soil, meaning that the nutrients applied did not accumulate in the soil over time to a significant degree. The integrated nutrient application had a limited impact on soil electrical conductivity due to the low residual effect of the applied inputs and the soil's high buffering capacity [5,4].

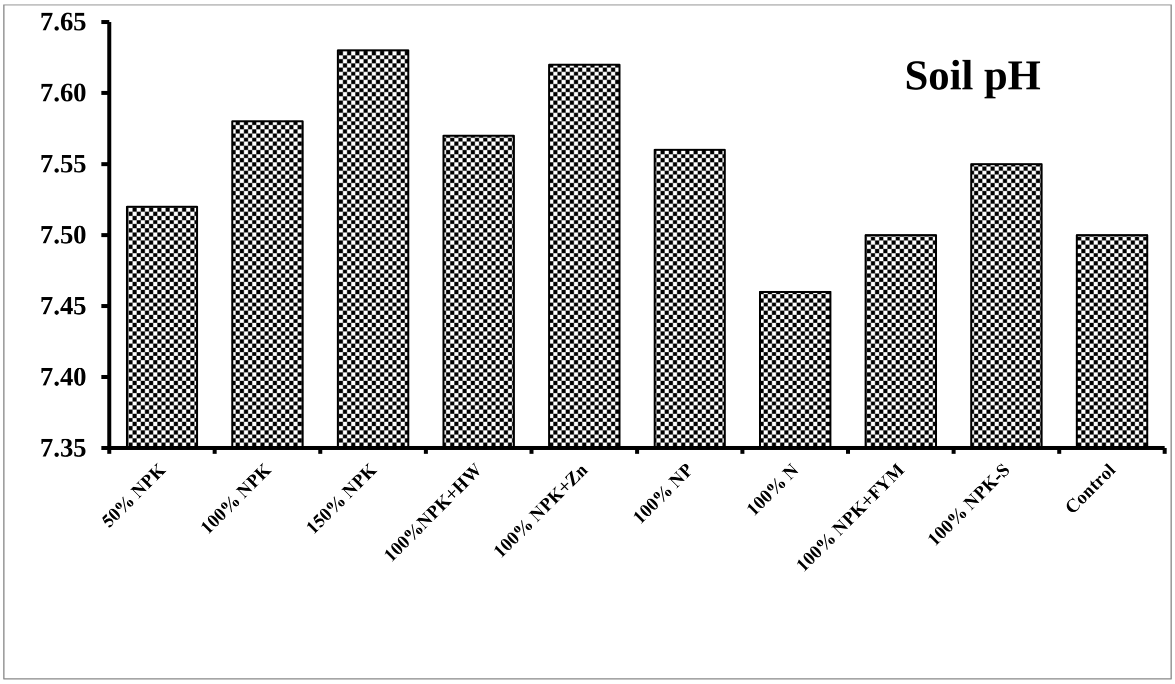

Fig. 1. Effect of chemical fertilizer and organic manure on soil pH

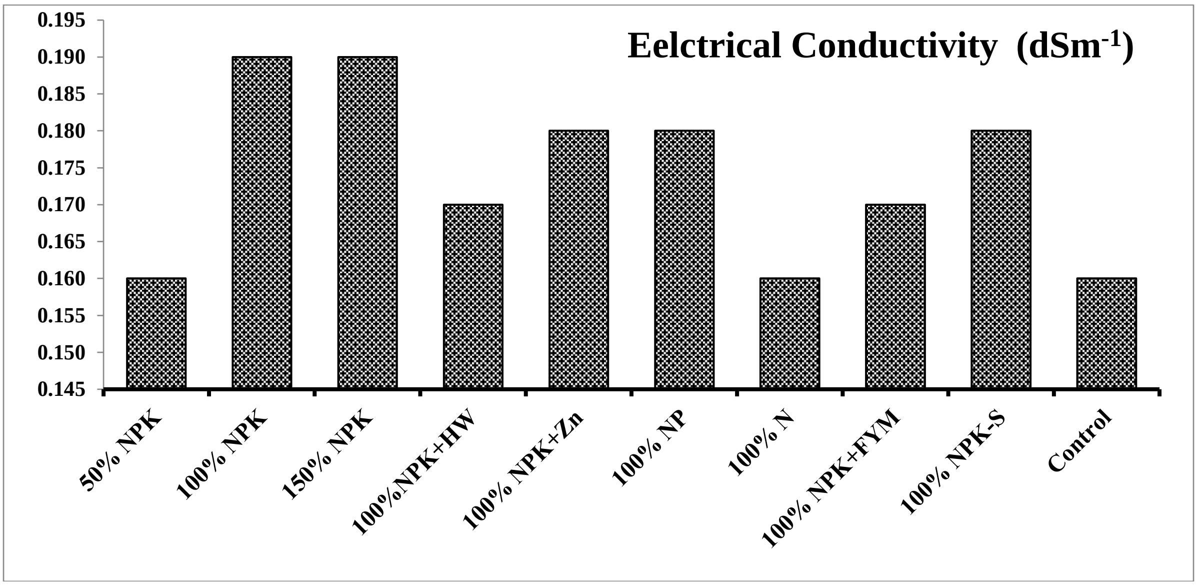

Fig. 2. Effect of chemical fertilizer and organic manure on soil electrical conductivity

3. EFFECT OF CHEMICAL FERTILIZER AND ORGANIC MANURE ON SOIL ORGANIC CARBON

Soil organic carbon is a critical soil property that plays an essential role in determining soil productivity. Its significance in preserving soil fertility and supporting crop productivity has been acknowledged for centuries. Soil organic carbon serves as a crucial and general indicator of the level of biological activity in soil. Maintaining adequate levels of soil organic carbon is especially vital in intensive cropping systems. Organic carbon serves as an indicator of the availability of essential plant nutrients in the soil. However, it’s worth noting that continuous reliance on inorganic fertilisers has been observed to decrease the organic carbon content of the soil. This reduction in soil organic carbon underscores the importance of adopting sustainable agricultural practices to mitigate the decline in soil health caused by excessive use of inorganic fertilizers. An increase in organic matter content was attributed to the direct incorporation of organic matter, better root growth, and more plant residue addition [6] in the evaluation of long-term fertility trials. highest organic C status due to the application of a higher rate of FYM with a half dose of N and P fertiliser. Organic C content increased significantly in cultivated soil over the control plot under the long-term soybean-wheat cropping systems [7]. A decline in organic carbon is a result of the continuous application of N fertiliser alone, while the balanced use of chemical fertiliser along with organic manure improves organic carbon.

Additionally, it has been reported that the incorporation of organic material into the soil not only enhances crop production but can also help mitigate the rate of soil acidification in agricultural ecosystems. This finding underscores the multifaceted benefits of incorporating organic matter into agricultural systems, as it can positively impact both crop yields and soil health by counteracting soil acidification [8].

4. EFFECT OF CHEMICAL FERTILIZER AND ORGANIC MANURE ON AVAILABLE NITROGEN

One of the most essential nutrients for the growth of plants is nitrogen. Changes in the quantity of organic matter in the soil have significant effects on the dynamics of nitrogen in the soil. The available nitrogen (N) content of the soil was found to rise slightly when 100% NPK and farmyard manure (FYM) treatments were used in a study that was conducted over 47 years of continuous cropping. According to [4], this suggests that organic matter inputs in the form of inorganic and FYM may significantly raise the amount of nitrogen found in the soil. However, the N content in the soil exhibited even further enhancement when an integrated approach of applying both manure and fertiliser was adopted. This suggests that the combination of organic and inorganic inputs had a synergistic effect on increasing soil nitrogen content. The presence of organic matter within the root zone was likely a contributing factor to this favourable condition, as it can enhance nutrient availability and support plant growth. The integrated use of manure and fertiliser appears to promote a more conducive environment for nutrient retention and utilisation in the soil, resulting in higher nitrogen content [9].

This integrated approach was found to enhance the efficiency of nitrogen utilisation compared to using an imbalanced fertiliser application. This effect could be attributed to the presence of a higher root biomass in the rhizosphere zone of the soil, particularly in the upper soil layers, and this root biomass decreased with increasing soil depth. Similar observations were made regarding the importance of integrated nutrient management and the influence of root biomass on nutrients [3,10].

The Long-Term Manurial Experiments' results showed that the amount of phosphorus (P) or potassium (K) supplied had no effect on the availability of N. However, when P and K were used without FYM, the amount of accessible N was reduced [11]. Furthermore, each increase in the rate of FYM treatment was associated with a rise in the amount of soil N that was available [12]. When 100 percent NPK + FYM treatment was used, the soil's available N content also increased, which was attributed to the Inceptisol soil type's higher organic carbon content. In plots receiving only FYM, continued cropping without fertilisation caused a decrease in the available N status. However, the availability of nitrogen has been significantly enhanced by applying nitrogen fertilisers on a regular basis. This rise was attributed to the use of organic manure, which improved the conversion of organically bound nitrogen into inorganic forms by increasing the activity of soil microorganisms [13].

5. EFFECT OF CHEMICAL FERTILIZER AND ORGANIC MANURE ON AVAILABLE PHOSPHORUS

After a building in the available P status of the soil past the initial value recorded in 1972, two particular fertiliser treatments-the 100% NPK + FYM treatments and the 150% NPK therapy-saw an apparent increase in soil phosphorus (P) levels. The P status of the soil was higher than the 1972era value of reference. According to many Long-Term Fertiliser Experiments (LTFEs) carried out across the nation, the use of nitrogen (N) alone in fertilisers may cause a rapid depletion of phosphorus (P) in the soil. The buildup of available phosphorus in soil resulting from the application of NPK fertilisers, either alone or in combination with organic materials, may be attributed to several factors. One contributing factor is the release of organic acids during the decomposition process. These organic acids, as reported by studies such as those conducted by [14,15]; play a crucial role in solubilizing native phosphorus in the soil, making it more readily available for plant uptake.

Additionally, the organic matter present in conjunction with fertilisers forms a protective cover for sesquioxides in the soil. This covering has the effect of rendering sesquioxides less active, thereby reducing the soil's capacity to fix phosphate. Ultimately, this reduction in phosphate fixing capacity contributes to the release of a greater quantity of phosphorus into the soil.

6. EFFECT OF CHEMICAL FERTILIZER AND ORGANIC MANURE ON AVAILABLE POTASSIUM

The soil's potassium (K) availability was significantly boosted throughout an extended soybean experiment cultivated on black soil. The application of farmyard manure (FYM), along with organic nitrogenous and phosphatic fertilisers, was blamed for this increase. By combining organic materials with fertilisers, the soil's potassium status was noticeably improved, making more of this crucial nutrient available for plant uptake, [14]. identified trends in soil potassium (K) availability carried on by inconsistent applications of fertiliser, such as nitrogen in addition to phosphorus (NP) or nitrogen alone (N). The appropriate fertiliser dose was consistently combined with organic matter to produce the highest amount of easily available potassium. [10] found that maintaining soil fertility over the long term depended significantly on the integrated use of farmyard waste and chemical fertilisers. In addition to direct potassium supplementation, a reduction in potassium fixation and the release of potassium from the soil as a result of interactions between organic matter and clay can both be attributed to the increase in potassium the availability that results from the addition of organic manures [15] similar found an increase in the amount of potassium that was readily accessible when organic and inorganic fertilisers were combination.

7. EFFECT OF CHEMICAL FERTILIZER AND ORGANIC MANURE ON AVAILABLE SULPHUR

The treatment involving farmyard manure (FYM) with balanced, optimum doses of fertilisers was found to have the highest sulphur (S) level in the soil. The S content was increased by additional nutrient supplementation that was carried out using the optimum fertiliser and FYM doses [16]. The surface soil's S level increased in all other treatments, and the amount of this rise correlated with the amount of fertiliser used. According to [17], treatments with 150% NPK and 100% NPK + FYM showed the greatest increases in S content. According to [18], the addition of FYM creates optimal conditions for higher nutrient utilisation efficiency and is associated with the greatest S content.

However, when only nitrogen (N) was applied without other nutrients, the available S content in the surface soil was notably low. The available S amount in the surface soil was, however, significantly reduced when only nitrogen (N) and no additional fertilisers were added. With higher levels of fertiliser application, available S content increased and peaked at 37.79 kg ha-1 when

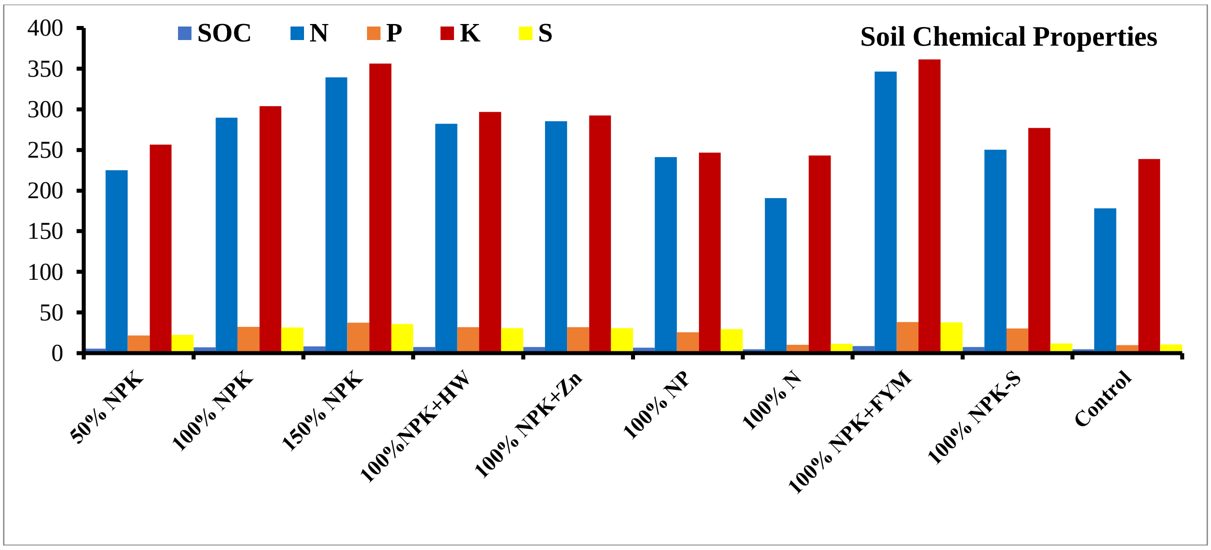

Fig. 3. Effect of chemical fertilizer and organic manure on soil chemical properties

100% NPK + FYM was used. It's important to note that there wasn't much of a difference in the amount of S between post-harvest soil samples and pre-sowing soil. Similar patterns of sulphur availability were also observed in the study.

8. EFFECT OF CHEMICAL FERTILIZER AND ORGANIC MANURE ON MICRONUTRIENT

In the study, DTPA-Cu levels improved in the balanced and imbalanced fertiliser treatments compared to the control group. The treatments combining NPK and FYM (with zinc) demonstrated the highest DTPA-Cu levels [19]. In addition, balanced fertiliser treatments with FYM alone or combined with (NPK + FYM and NPK + FYM + Zn) showed considerably higher DTPA-Fe (iron) content than other treatments across a 10-year rice-wheat cropping sequence. With the addition of a single superphosphate, this increase in DTPA-Fe further increased [8]. The study additionally found that the application of FYM caused cationic micronutrients in the soil to practice a buildup. The chelation approach may be responsible for this rise in availability [20]. It's interesting to know that soils with greater pH values have been found with increased copper (Cu) solubility. The amount of Cu complexation in the soil solution is related to the pH of the soil. Although the total copper solubility in the soil increases in high pH circumstances, the free Cu^{2+} solubility remains low [21-25], the addition of farmyard manure (FYM) improved the soil's availability of manganese (Mn). The increase may be due to the release of Mn^{2+} ions by organic matter's organic ligands. Furthermore, the presence of organic matter rapidly up the conversion of Mn^{4+} to Mn^{2+}, resulting in increased amounts of available Mn. In a different study on Chromusterts soil, it was noted that the application of larger doses of NPK fertilisers resulted in an increase in the available Mn status.

9. CONCLUSION

The above literature review highlights the critical importance of long-term fertilizer experiments (LTFE) in various dimensions, including environmental sustainability and soil health. As the country faces the challenge of feeding a growing population, the spotlight is squarely on the sustainable maintenance of soil fertility, especially in the context of intensive crop cultivation. The goal is to achieve higher grain production per unit area, per unit time, and per unit input, all while preserving the integrity of the soil environment and soil health. To meet this goal, continuous monitoring of changes in nutrient dynamics is essential. LTFE serves as a valuable resource, providing both soil and plant materials for further scientific research. These experiments offer a foundation for investigating the intricate processes that govern soil fertility, plant productivity, and the quality of water, soil, and air. LTFE plays a pivotal role in advancing our understanding and practices related to sustainable agriculture and environmental stewardship.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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