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Long-term application of fertilizers and manure on soil properties and yield of groundnut grown on Alfisols

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Abstract

An experiment on long-term application of fertilizers and manure in groundnut grown on Alfisol was initiated in the year 1981 during *kharif* season at ANGRAU, Regional Agricultural Research Station, Tirupati, Andhra Pradesh, India. The same experiment was used for the present investigation to study the influence of continuous application of fertilizer and manure on various soil properties during *kharif*, 2023. The experiment consisted of eleven treatments, however, only seven treatments were selected for the present research study, each replicated four times in a randomized block design. The treatments include T₁: Control (no manure or fertilizers), T₂: Farm yard manure @ 5 t ha⁻¹ (once in 3 years), T₃: 20 kg N ha⁻¹ + 10 kg P ha⁻¹, T₄: 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹, T₅: 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + 250 kg gypsum ha⁻¹ (top dressing), T₆: 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + lime 100 kg ha⁻¹ (top dressing), T₇: 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + 250 kg gypsum ha⁻¹ (top dressing) + ZnSO₄ 25 kg ha⁻¹ once in 3 years (as basal, once in 3 years). The physical, physico-chemical and chemical properties were estimated in soil at pre-sowing and post-harvest of groundnut crop. The results revealed that long-term application of fertilizers and manure did not show any significant influence on soil properties at pre-sowing of groundnut crop. However, the influence was significant in post-harvest soils. The bulk density was significantly decreased in the application of FYM @ 5 t ha⁻¹ once in 3 years (T₂) (1.34 Mg m⁻³) and highest bulk density was recorded in control (1.48 Mg m⁻³). Similarly, the treatments showed the highest aggregate stability in FYM application (T₂) (30.41%) followed by 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ (T₄) (28.69%) and the lowest was recorded in control (T₁). The long-term application of fertilizer caused acidity in all the treatments but change in pH was minimum with FYM application followed by control. The lowest pH of 6.20 was recorded in 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + 250 kg gypsum ha⁻¹ (top dressing) (T₅). However, the treatment did not show any influence in soluble salts content. The organic carbon was significantly influenced in 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + 250 kg gypsum ha⁻¹ (top dressing), + ZnSO₄ 25 kg ha⁻¹ once in 3 years (T₇) (0.39%) followed by FYM @ 5 t ha⁻¹ once in 3 years (T₂) (0.38%) and lower was in control (T₁). The highest available N (194 kg ha⁻¹), available P (58.70 kg ha⁻¹) and available K (334 kg ha⁻¹) were recorded in (T₇) and (T₄) 138,43.30 and 218 kg ha⁻¹ respectively. Similarly, higher pod yield (1821 kg ha⁻¹) and haulm yield (3458 kg ha⁻¹) were recorded in (T₇) and 1728, 3437 kg ha⁻¹ T₆ respectively and 1785, 3262 kg ha⁻¹ (T₂) respectively and lower was in control. The continuous cropping and application of fertilizers and manure for 43 years showed significant influence on soil properties in rainfed groundnut crop grown on Alfisols.

Keywords: Long-term fertilizer experiment, soil properties, rainfed groundnut

Introduction

Soil is a vital natural resource and soil health reflects the integrated effect of management practices on various soil properties that determine crop productivity and sustainability (Sharma *et al.*, 2005) [22]. In Indian agriculture, continuous cultivation of high-yielding varieties along with the extensive use of high-analysis chemical fertilizers has become inevitable to meet the growing food demand. However, such practices have accelerated the mining of essential nutrients from the soil. The long-term application of chemical fertilizers alone may adversely affect soil properties and reduce soil productivity over time. Long-term experiments conducted at fixed sites under continuous cropping systems are essential for monitoring changes in soil quality and crop yield sustainability. These experiments also provide valuable insights for developing efficient fertilizer management strategies while minimizing environmental

degradation. Maintaining soil health is crucial not only for maximizing agricultural production but also for sustaining higher productivity levels in cropping systems (Velu and Subramaniam, 2012) [30].

Long-term fertilizer experiments (LTFEs) play a crucial role in understanding the changes in soil physical, physicochemical and chemical properties, as well as crop productivity, under continuous fertilization and cropping. The decline in soil fertility due to imbalanced fertilizer use has been recognized as a major constraint to crop yield. LTFEs serve as valuable repositories of long-term data that help in assessing the sustainability of intensive agricultural practices. Continuous application of fertilizers and manures significantly alters soil properties and these experiments are designed to evaluate the extent to which soils can sustain high production levels without undergoing depletion or deterioration. Hence the present study is taken up in an undergoing long-term fertilizer experiment in rainfed groundnut monocropping at Regional Agricultural Research Station, Tirupati, which is initiated in *Kharif*, 1981. The effect of continuous cropping and application of fertilizers and manure on soil properties were studied during *kharif*, 2023.

Materials and Methods

The present investigation was carried in an undergoing long-term fertilizer experiment on Alfisols (Typic Rhodustalf) at Regional Agricultural Research Station, Tirupati, Tirupati district of Andhra Pradesh during the *kharif*, 2023 which is initiated in 1981. The experiment consisted of eleven treatments, however, only seven treatments were selected for the present research study, each replicated four times in a randomized block design. The treatments include T₁: Control (no manure or fertilizers), T₂: FYM @ 5 t ha⁻¹ (once in 3 years), T₃: 20 kg N ha⁻¹ + 10 kg P ha⁻¹, T₄: 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹, T₅: 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + 250 kg gypsum ha⁻¹ (top dressing), T₆: 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + lime 100 kg ha⁻¹ (top dressing), T₇: 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + 250 kg gypsum ha⁻¹ (top dressing) + ZnSO₄ 25 kg ha⁻¹ once in 3 years (as basal, once in 3 years). The nutrients NPK were applied through the fertilizers like urea, single super phosphate and muriate of potash. The farmyard manure and ZnSO₄ were applied once in the three years as per treatments the test crop was groundnut, variety TCGS 1694 (Visishta). The crop was sown on 16-07-2023 and harvested on 19-11-2023. The soil samples were collected at pre-sowing and post-harvest at 0-15 cm as per treatments and analysed for physical, physico-chemical and chemical properties. The bulk density and particle density was determined by core sampler method (Blake, 1965) [2], Aggregate stability by Yodanis apparatus (Van Bavel, 1949) [28]. Soil pH was determined by potentiometry (Jackson, 1973) [9], electrical conductivity by conductometry (Jackson, 1973) [9], organic carbon by wet digestion method (Walkley and Black, 1934) [31]. The available nitrogen was determined by alkaline permanganate method (Subbaiah and Asija, 1956) [26], phosphorus by (Olsen *et al.*, 1954) [16] and available potassium by Jackson (1973) [9].

Results and Discussion

Bulk density

The long-term application of fertilizer and manure on bulk density of soil at pre-sowing was found to be non-significant Table (1). The bulk density of soil at pre-sowing was ranged from 1.34 to 1.48 Mg m⁻³. The control (T₁) recorded numerically higher bulk density (1.48 Mg m⁻³) whereas, the lower bulk density (1.34 Mg m⁻³) was recorded in the application FYM @ 5

t ha⁻¹ once in 3 years (T₂). However, the treatment exhibited a significant influence on bulk density of soil at post-harvest of groundnut during *kharif*, 2023. The bulk density of soil at post-harvest was ranged from 1.38 to 1.56 Mg m⁻³. The control (T₁) for 43 years registered significantly the highest bulk density (1.56 Mg m⁻³), which was statistically on par with the application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) + ZnSO₄ @ 25 kg ha⁻¹ once in 3 years (T₇) and 20 kg N ha⁻¹ + 10 kg P ha⁻¹ (T₃), 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) (T₅), 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + lime @ 100 kg ha⁻¹ (top dressing) (T₆) and were higher over the application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ (T₄) and FYM @ 5 t ha⁻¹ once in 3 years (T₂). The lowest bulk density (1.38 Mg m⁻³) was registered in FYM @ 5 t ha⁻¹ once in 3 years (T₂).

The lower bulk density of soil due to application of FYM @ 5 t ha⁻¹ once in 3 years (T₂) might be due to higher organic carbon, more pore space and good soil aggregation (Selvi *et al.*, 2005) [21], Hemanth *et al.* (2022) [8]. This result is in accordance with Sheeba and Kumaraswamy (2001) [23] who observed decrease in bulk density with increase in organic matter content. Similar, addition of organic matter may delay the development of hard pan in soil there by lowering of bulk density of soil. Jamunaelumalai *et al.* (2025) [10] reported that bulk density was reduced through the application of organic manure as compared to inorganic fertilizers.

Particle density

The continuous application of fertilizers and manure since 1981 on particle density of soil at pre-sowing was found to be non-significant Table (1). The particle density of soil at pre-sowing was ranged from 2.47 to 2.56 Mg m⁻³. The control (T₁) recorded numerically higher particle density (2.56 Mg m⁻³) whereas, lower particle density (2.47 Mg m⁻³) was recorded in 20 kg N ha⁻¹ + 10 kg P ha⁻¹ (T₃). Similarly, long-term application of fertilizers and manure exhibited a non-significant influence on particle density at post-harvest of groundnut during *kharif*, 2023. The particle density of soil at post-harvest was ranged from 2.48 to 2.60 Mg m⁻³. The control (T₁) recorded numerically higher particle density (2.60 Mg m⁻³) whereas, lower particle density (2.48 Mg m⁻³) was registered in 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + lime @ 100 kg ha⁻¹ (top dressing) (T₆).

The results indicated that long-term application of fertilizers and manure had non-significant effect on particle density of soil at both stages of pre-sowing and post-harvest of the crop during *kharif*, 2023. The lower particle density of soil due to application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + lime @ 100 kg ha⁻¹ (top dressing) (T₆) might be due to higher organic matter content of the soil, better aggregation and a consequent increase in volume of micropores and increased root growth in the fertilizers and manure treatments. This is in conformity with findings of Hatti *et al.* (2008) [7], Ortas and Lal (2013) [17] and Salmabanu *et al.* (2016) [19].

Aggregate stability

The long-term application of fertilizer and manure on aggregate stability of the soil at pre-sowing was found to be non-significant Table (1). The aggregate stability of soil at pre-sowing was ranged from 28.69 to 30.41%. The application of FYM @ 5 t ha⁻¹ once in 3 years (T₂) registered numerically higher aggregate stability (30.41%) whereas, lower aggregate stability (28.69%) was observed in 20 kg N ha⁻¹ + 10 kg P ha⁻¹ (T₃).

However, the long-term application of fertilizers and manure

showed a significant influence on aggregate stability at post-harvest soils of groundnut during *kharif*, 2023. The aggregate stability of soil at post-harvest was ranged from 28.91 to 33.42%. The application of FYM @ 5 t ha⁻¹ once in 3 years (T₂) registered numerically higher aggregate stability (33.42%) followed by 20 kg N ha⁻¹+10 kg P ha⁻¹+25 kg K ha⁻¹+ gypsum @ 250 kg ha⁻¹ (top dressing) (T₅), 20 kg N ha⁻¹+10 kg P ha⁻¹+ 25 kg K ha⁻¹+ gypsum @ 250 kg ha⁻¹ (top dressing) + ZnSO₄ @ 25 kg ha⁻¹ once in 3 years (T₇), 20 kg N ha⁻¹+10 kg P ha⁻¹(T₃), 20 kg N ha⁻¹+10 kg P ha⁻¹+25 kg K ha⁻¹+ lime @100 kg ha⁻¹ (top dressing) (T₆), control (T₁), while lower aggregate stability (28.91%) was observed in (T₄).

Increase of soil aggregate stability due to application of FYM @ 5 t ha⁻¹ once in 3 years (T₂) might be due to the addition of organic matter through organic manure and root biomass to soil, induced the formation of macro aggregates as they are the carbon source for microbial activities and production of microbial derived binding agents (Hatti *et al.*, 2008^[8] and Chen *et al.*, 2010)^[3], Hemanth *et al.* (2022)^[7]. It was also reported that stabilization is favoured through the binding action of humic substances, polysaccharides and fungal hyphae (Graham *et al.*, 2002)^[6]. Similar, Swamy *et al.* (2019)^[27] observed that application of FYM improved aggregate stability (40%) and reduced the bulk density (1.38 Mg m³) as compared to control (34.83% and 1.45 Mg m³) in *kharif* groundnut in an Alfisol of Anantapuramu. Jamunaelumalai *et al.* (2025)^[10] report that soil physical parameter such as pore space, aggregate stability improved through the application of organic manure as compared to inorganic fertilizers and soil microbial count also increased in the organic manure applied treatments.

Soil reaction (pH)

The long term application of fertilizer and manures on pH of the soil at pre-sowing was found to be non-significant since Table (1). The pH of the soil at pre-sowing was ranged from 6.32 to 6.53. The highest pH of the soil (6.53) was registered in farm yard manure application (FYM) @ 5 t ha⁻¹ once in three years (T₂) followed by control (T₁) while the lowest (6.32) was observed in application of 20 kg N ha⁻¹+10 kg P ha⁻¹+25 kg K ha⁻¹ (T₄). However, the pH of the soil at post-harvest was significantly influenced by the treatments and ranged from 6.21 to 6.45. The significantly higher pH of the soil (6.45) was registered in FYM application @ 5 t ha⁻¹ once in three years (T₂) followed by control (T₁) whereas, lower pH (6.21) was observed in 20 kg N ha⁻¹+10 kg P ha⁻¹+25 kg K ha⁻¹ (T₄).

Analysis of data at harvest showed a slight decrease in soil pH in all the treatments including control when compared to the initial soil pH (6.7) recorded in 1981. Application of FYM resulted in maintenance of the highest pH while 20 kg N ha⁻¹+10 kg P ha⁻¹+25 kg K ha⁻¹ (T₄) recorded the lowest pH as compared to all other treatments. This may be due to the acidifying effect of different chemical fertilizers and release of H⁺ ions in to the soil. Naga Madhuri *et al.* (2017)^[15] reported that the increase in pH of soil with the application of FYM was due to deactivation of Al³⁺ and concomitant release of basic cations upon decomposition. These results were in accordance with the finding of Kumari *et al.* (2013)^[12], Salmabhanu. *et al.* (2017)^[18].

Soil electrical conductivity

The EC of the soil at pre-sowing was non-significantly influenced by various treatments imposed continuously Table (1). The EC of soil at pre-sowing was ranged from 0.08 to 0.10 dSm⁻¹. The application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹+25 kg K

ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) + ZnSO₄ @ 25 kg ha⁻¹ once in 3 years (T₇) observed numerically the highest the (0.10 dSm⁻¹) while lower EC (0.08 Mg m⁻³) was registered in control (T₁). The long-term application of fertilizers and manure exhibited a non-significant influence on EC of soils at harvest in groundnut during *kharif*, 2023. The EC of soil after the harvest of crop was ranged from 0.08 to 0.10 dSm⁻¹. The application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹+25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) + ZnSO₄ @ 25 kg ha⁻¹ once in 3 years (T₇) registered numerically higher EC (0.10 dSm⁻¹) whereas lower EC (0.08 dSm⁻¹) was recorded in control (T₁).

Low initial EC status of the soil was maintained even after more than four decades of cropping. Similar results were earlier reported by Salma *et al.* (2017)^[18] that the accumulation of salts was not observed due to continuous application of manures and inorganic fertilizers to rainfed groundnut over a period of 34 years in both the surface and subsurface soil layers. These findings are in close agreement with the reported of several researchers, including Yamini *et al.* (2015)^[32] and Shivashankar *et al.* (2018)^[24].

Organic carbon (OC)

The OC of the soil at pre-sowing was significantly influenced by various treatments imposed continuously since 1981 Table (1). The organic carbon content of the soil at pre-sowing ranged from 0.26 to 0.39%. The organic carbon (0.39) was significantly higher due to application FYM @ 5 t ha⁻¹ once in 3 years (T₂) whereas lower OC of the soil (0.26), was recorded in control (T₁). The OC of the soil at post-harvest was significantly influenced by the treatments and ranged from 0.27 to 0.39%. However, significantly higher OC of the soil (0.39) was recorded in the treatment of application of FYM @ 5 t ha⁻¹ once in 3 years (T₂) followed by 20 kg N ha⁻¹ + 10 kg P ha⁻¹+25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) + ZnSO₄ @ 25 kg ha⁻¹ (T₇), 20 kg N ha⁻¹+10 kg P ha⁻¹ (T₃), 20 kg N ha⁻¹+10 kg P ha⁻¹+25 kg K ha⁻¹+ gypsum @ 250 kg ha⁻¹ (top dressing) (T₅) and were higher over the application of 20 kg ha⁻¹N +10 kg P ha⁻¹+25 kg K ha⁻¹ (T₄). The lower OC of the soil (0.27) was observed in control (T₁).

From the above said results, there was a slight increase in organic carbon content of soil in all the treatments including control when compared initial organic carbon of soil (0.18). The highest organic carbon of the soil was recorded in the treatment of application of FYM @ 5 t ha⁻¹ once in 3 years (T₂). Maintaining significantly higher organic carbon, the control (T₁) observed the lower organic carbon as compared to all the other treatments. Continuous application of FYM and other organics contributed to higher accumulation of organic matter due to the addition of stable carbon fractions and also improving the microbial activity of the soil. Similar observations were also reported by Kundu *et al.* (2017)^[13].

Available nitrogen

Available nitrogen in soil at pre-sowing and after-harvest as effected by long term application of manures and fertilizers is presented in Table (2). The long-term application of fertilizers and manure on available nitrogen of the soil at pre-sowing was found to be non-significant since 1981. The available nitrogen of the soil at pre-sowing was ranged from 189 to 217 kg ha⁻¹. The application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ (T₄) recorded numerically higher available nitrogen (217) whereas lower available nitrogen (189) was noticed in control (T₁).

Long-term application of fertilizers and manure exhibited a significant influence on available nitrogen of the soil at post-

harvest of groundnut during *kharif*, 2023. The available nitrogen of the soil after harvest of the crop was ranged from 138 to 194 kg ha⁻¹. The application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ (T₄) recorded significantly higher available nitrogen (194 kg ha⁻¹), which was statistically on par with the application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) + ZnSO₄ @ 25 kg ha⁻¹ once in 3 years (T₇) and 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + lime @ 100 kg ha⁻¹ (top dressing) (T₆), 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) (T₅), 20 kg N ha⁻¹ + 10 kg P ha⁻¹ (T₃) and were higher over the application of FYM @ 5 t ha⁻¹ once in 3 years (T₂). The lowest available nitrogen (138 kg ha⁻¹) was recorded in control (T₁).

From the above said results, it was clear that the available nitrogen in soil deceased in all the treatments including control when compared to the initial available nitrogen recorded in 1981. Application of 20 kg N + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ (T₄) resulted in maintenance of higher available nitrogen when compared to control (T₁), which registered the lower available nitrogen as compared to all other treatments. Similar, results were earlier registered by Gowda *et al.* (2017) [5], who studied the nutrients availability in soil under long term fertilization with inorganic fertilizers alone or in combination with organics. The results also envisaged that application of inorganics alone resulted in decreased nutrients status over balanced fertilizer application.

Available phosphorus

The available phosphorus in soil at pre-sowing and after harvest as effected by long-term application of manure and fertilizers Table (2). The available phosphorus of the soil at pre-sowing was non-significantly influenced by various treatments imposed continuously. The available phosphorus at pre-sowing was ranged from 20.14 to 31.42 kg ha⁻¹. The application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) + ZnSO₄ @ 25 kg ha⁻¹ once in 3 years (T₇) observed numerically higher available phosphorus (31.42 kg ha⁻¹) whereas lower available phosphorus (21.14 kg ha⁻¹) was recorded in control (T₁).

The available phosphorus after harvest of the crop was significantly influenced by treatments and ranged from 43.30 to 64.60 kg ha⁻¹. Application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) + ZnSO₄ @ 25 kg ha⁻¹ once in 3 years (T₇) recorded significantly higher available phosphorus (64.60 kg ha⁻¹), which was statistically on par with the application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ (T₄), 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ (T₃), 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) (T₅), 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + lime @ 100 kg ha⁻¹ (top dressing) (T₆) and were higher over the application of FYM @ 5 t ha⁻¹ once in 3 years (T₂). The lowest available phosphorus (43.30 kg ha⁻¹) was observed in control (T₁).

From the above said results, it was clear that the available phosphorus in the soil deceased in all the treatments including control when compared to the initial available phosphorus (47.70 kg ha⁻¹) recorded in 1981. Application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) + ZnSO₄ @ 25 kg ha⁻¹ once in 3 years (T₇) resulted in maintenance of higher available phosphorus, after continuous application of fertilizers and manure since 1981 years under rainfed conditions. The depletion of available P was mainly due to the crop uptake since 43 years irrespective of its application from the soil. This situation is ascribed to lower dose of P application to crop (10 kg P ha⁻¹) against the recommended dose of 17.5 kg P ha⁻¹. The

decrease of soil available P in the treatments where P was included might be due to the blocking of available phosphorus which was attributed to formation of tricalcium phosphate. This formation of tricalcium phosphate might be due to the presence of considerable amount of calcium. Similar, results were earlier reported by Parvathi *et al.* (2015) [18], Yamini *et al.* (2015) [32], Salma *et al.* (2017) [20] and Kumar *et al.* (2024) [12].

Available potassium

The available potassium of the soil at pre-sowing was non-significantly influenced by various treatments imposed continuously. The available potassium at pre-sowing was ranged from 336 to 353 kg ha⁻¹. Application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) + ZnSO₄ @ 25 kg ha⁻¹ once in 3 years (T₇) recorded numerically higher available potassium (353) whereas lower available potassium (336) was observed in control (T₁).

The critical analysis of the data indicated that available potassium of the soil decreased in all the treatments studied during *kharif*, 2023 as compared to the initial status (216 kg ha⁻¹) registered in the year, 1981. The available potassium post-harvest of the crop was ranged from 218 to 334 kg ha⁻¹. Application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) + ZnSO₄ @ 25 kg ha⁻¹ once in 3 years (T₇), recorded significantly higher available potassium (415 kg ha⁻¹), which was statistically on par with the application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) (T₅), FYM @ 5 t ha⁻¹ once in 3 years (T₂), 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + lime @ 100 kg ha⁻¹ (top dressing) (T₆) and were higher over the application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ (T₃). The lowest available potassium (218 kg ha⁻¹) in the soil was recorded in control (T₁).

From the above said results, it was clear that the available potassium in the soil deceased in all the treatments including control when compared to the initial available potassium recorded in 1981. Application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) + ZnSO₄ @ 25 kg ha⁻¹ once in 3 years (T₇) resulted in maintenance of higher available potassium. These decrease in available K was mainly due to the more uptake of K from the soil. The higher uptake of K was might be due to the getting higher haulm and pod yield in some of the *kharif* seasons in which favourable environmental conditions prevailed. Further, the crop suffered with lower dose of K than recommend to the region (33 kg ha⁻¹). This has been happened since inception of the trial fixed in the year, 1981. Intensive cropping with high yielding crop varieties led to depletion of K from soil which was evident from a number of long-term field experiments conducted across the country under AICRP program of ICAR (Anand Swarup, 2002), similar results were reported by Shivashankar *et al.* (2018) [23].

Pod yield

The long-term application of fertilizers and manure revealed a significant influence on pod yield of groundnut crop during *kharif*, 2023 and the data is presented in Table (2). Among of different treatments, significantly the higher pod yield (1821 kg ha⁻¹) was recorded with application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + lime @ 100 kg ha⁻¹ (top dressing) (T₆), FYM @ 5 t ha⁻¹ (T₂), 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) (T₅), 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ (T₄) and on par the application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) + ZnSO₄ @ 25 kg ha⁻¹ once in 3 years (T₇). The lower pod yield

(1271 kg ha⁻¹) was recorded in control (T₁).

The higher pod yield in the application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + lime @100 kg ha⁻¹ (top dressing) might be due to liming improved soil physical properties, such as aggregation and aeration and stimulated microbial activity, resulting in enhanced nutrient mineralization and uptake. The combined application of NPK fertilizers with lime thus ensured balanced nutrition, improved root growth, enhanced nodulation and efficient translocation of assimilates, culminating in higher pod yield of groundnut. The results are in agreement with Vasuki (2020) [29].

Haulm yield

The treatments exhibited a significant effect on haulm yield of groundnut crop during *kharif*, 2023 and data is presented in Table (2). Significantly the higher haulm yield (3458 kg ha⁻¹) was recorded with application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) + ZnSO₄ @ 25

kg ha⁻¹ once in 3 years (T₇), 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + lime @100 kg ha⁻¹ (top dressing) (T₆), FYM @ 5 t ha⁻¹ (T₂), 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ (T₄), 20 kg N ha⁻¹ + 10 kg P ha⁻¹ (T₃), 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (top dressing) (T₅). The lower haulm yield (2410 kg ha⁻¹) was recorded in control (T₁).

Application of 20 kg N ha⁻¹ + 10 kg P ha⁻¹ + 25 kg K ha⁻¹ + gypsum @ 250 kg ha⁻¹ (Top dressing) + ZnSO₄ @ 25 kg ha⁻¹ once in 3 years (T₇) increased haulm yield, which might have provided that sufficient and balanced nutrients in readily available form throughout the growth period of the crop and the increased availability of plant nutrients, their uptake leading to the greater photosynthesis production of metabolites and enzymatic activities might have increased nodulation and extensive root system and the greater production of metabolites and their translocation to various sinks, especially the productive structures could have helped to increased haulm yield (Singh et al., 2023) [24].

Table 1: Effect of long -term application of fertilizers and manure on soil physical, physico-chemical properties at pre-sowing and post-harvest of groundnut crop during *kharif*, 2023.

Treatments	BD (Mg m ⁻³)		PD (Mg m ⁻³)		Aggregate stability (%)		pH		EC (dSm ⁻¹)		OC (%)	
	Pre sowing	Post harvest	Pre sowing	Post harvest	Pre sowing	Post harvest	Pre sowing	Post harvest	Pre sowing	Post harvest	Pre sowing	Post harvest
T ₁ : control	1.48	1.56	2.56	2.60	29.09	29.34	6.40	6.42	0.08	0.08	0.27	0.27
T ₂ : FYM @ 5 t ha ⁻¹ once in 3 years	1.34	1.38	2.53	2.55	30.41	33.42	6.46	6.45	0.08	0.08	0.34	0.38
T ₃ : 20 kg N ha ⁻¹ + 10 kg P ha ⁻¹	1.40	1.47	2.47	2.50	29.45	30.56	6.24	6.26	0.09	0.09	0.33	0.35
T ₄ : 20 kg ha ⁻¹ N + 10 kg P ha ⁻¹ + 25 kg K kg ha ⁻¹	1.42	1.43	2.48	2.50	28.69	28.91	6.23	6.20	0.09	0.09	0.31	0.32
T ₅ : 20 kg N ha ⁻¹ + 10 kg P ha ⁻¹ + 25 kg K ha ⁻¹ + gypsum @ 250 kg ha ⁻¹ (top dressing)	1.40	1.46	2.52	2.55	30.03	33.02	6.26	6.20	0.09	0.09	0.32	0.34
T ₆ : 20 kg N ha ⁻¹ + 10 kg P ha ⁻¹ + 25 kg K ha ⁻¹ + lime @100 kg ha ⁻¹ (top dressing)	1.42	1.44	2.50	2.48	29.55	29.97	6.23	6.22	0.10	0.10	0.29	0.30
T ₇ : 20 kg N ha ⁻¹ + 10 kg P ha ⁻¹ + 25 kg K ha ⁻¹ + gypsum @ 250 kg ha ⁻¹ (top dressing) + ZnSO ₄ @ 25 kg ha ⁻¹ once in 3 years.	1.45	1.51	2.56	2.58	29.07	30.16	6.25	6.24	0.10	0.01	0.38	0.39
Mean	1.41	1.47	2.51	2.52	29.36	31.08	6.29	6.28	0.09	0.09	0.32	0.34
Initial (1981)	NA	NA	NA	NA	NA	NA	6.7	NA	0.08	0.18	NA	NA
Sem ±	0.04	0.05	0.08	0.08	0.92	0.89	0.09	0.04	0.01	0.01	0.03	0.01
CD@0.05	NS	0.14	NS	NS	NS	2.67	NS	0.14	NS	NS	NS	0.03
CV (%)	8.05	7.69	9.64	10.40	7.24	8.04	7.60	7.56	15.64	15.58	12.28	12.37

NA- Not availability, NS – Non significance

Table 2: Effect of long -term application of fertilizers and manures on soil chemical properties, pod and haulm yield at pre-sowing and post-harvest of groundnut crop during *kharif*, 2023.

Treatments	Avail.-N Kg ha ⁻¹		Avail. -P Kg ha ⁻¹		Avail.K Kg ha ⁻¹		Pod yield (kg ha ⁻¹)	Haulm yield (Kg ha ⁻¹)
	Pre sowing	Post harvest	Pre sowing	Post harvest	Pre sowing	Post harvest		
T ₁ : control	189	138	20.14	43.30	336	218	1271	2410
T ₂ : FYM @ 5 t ha ⁻¹ once in 3 years	194	169	25.34	48.90	343	313	1785	3262
T ₃ : 20 kg N ha ⁻¹ + 10 kg P ha ⁻¹	205	172	29.94	57.50	340	235	1553	2953
T ₄ : 20 kg ha ⁻¹ N + 10 kg P ha ⁻¹ + 25 kg K kg ha ⁻¹	217	194	25.27	58.70	345	326	1736	3213
T ₅ : 20 kg N ha ⁻¹ + 10 kg P ha ⁻¹ + 25 kg K ha ⁻¹ + gypsum @ 250 kg ha ⁻¹ (top dressing)	208	182	29.55	57.50	351	317	1783	2918
T ₆ : 20 kg N ha ⁻¹ + 10 kg P ha ⁻¹ + 25 kg K ha ⁻¹ + lime @100 kg ha ⁻¹ (top dressing)	211	182	28.12	54.20	343	312	1728	3437
T ₇ : 20 kg N ha ⁻¹ + 10 kg P ha ⁻¹ + 25 kg K ha ⁻¹ + gypsum @ 250 kg ha ⁻¹ (top dressing) + ZnSO ₄ @ 25 kg ha ⁻¹ once in 3 years.	215	185	31.42	64.60	353	334	1821	3458
Mean	204	174	20.02	54.67	345	294	1668	3093
Initial (1981)	NA	NA	47.60	NA	216	NA	NA	NA
Sem ±	4.76	3.02	2.23	1.61	5.19	9.08	150	273
CD@0.05	NS	8.75	NS	4.85	NS	27.25	50.04	91.17
CV (%)	8.18	8.94	6.51	9.13	5.02	11.55	10.23	11.25

NA- Not availability, NS – Non significance

Conclusion

Application of fertilizer and manure on long-term basis significantly effected post-harvest soil fertility in rainfed groundnut. The NPK application combined with gypsum and ZnSO₄ recorded the highest availability of major and secondary nutrients, highlighting the importance of balanced fertilization. Although soil physical and physico-chemical properties changed only slightly, nutrient status was markedly enhanced. Overall, application of FYM and balanced application of fertilizers along with amendments was more effective than single nutrients application or control in sustaining soil health and productivity.

Competing Interests

Authors have declared that no competing interests exist.

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