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PERFORMANCE OF AFRICAN SCARLET GARDEN EGG AND ASSOCIATED SOIL MICROBIAL POPULATIONS AS AFFECTED BY SINGLE SUPER PHOSPHATE FERTILISER IN IBADAN, NIGERIA

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ABSTRACT

Garden egg is a common vegetable with low yield due to high phosphorus fixation and nutrient mining in traditional land-use systems on many tropical soils. The amelioration of phosphorus deficiency in soil using Single Super Phosphate (SSP) fertiliser requires appropriate application levels to mitigate insufficiency or toxicity that could impair crop yield and soil health. Consequently, the influence of SSP fertiliser on garden egg performance and changes in soil microbial populations were investigated. Single Super Phosphate fertilisers at 0, 15, 30, and 45 kg P_2O_5/ha were evaluated in completely randomised design and randomised complete block design in pot and field conditions, respectively, with three treatment replicates. Data on growth, yield and microbes were analysed at $p<0.05$. The highest growth parameters observed were at 30 kg P_2O_5/ha, while the control had the lowest values. Applying 30 kg P_2O_5/ha significantly ($p<0.05$) enhanced garden egg fruit yield compared to the other treatments in the pot experiment. In the field, the respective fruit yield of 10695.00 and 12235.74 kg/ha at 30 and 45 kg P_2O_5/ha were significantly higher than the control (4763.70 kg/ha) but similar to 15 kg P_2O_5/ha (9313.80 kg/ha). The 30 kg P_2O_5/ha treatment resulted in a 14.82% yield increase compared to the 15 kg P_2O_5/ha treatment. Bacterial and fungal communities were higher at 30 kg P_2O_5/ha (7.0×10^4 and 0.5×10^6 cfu/g of soil) and lower at 45 kg P_2O_5/ha (4.5×10^4 and 0.2×10^6 cfu/g of soil). Application of single super phosphate at 30 kg P_2O_5/ha improved garden egg performance and associated microbial populations, and it is therefore recommended.

Keywords: Garden egg, *Solanum aethiopicum* gr. Gilo**,** Single super phosphate, soil health, soil microbial population

INTRODUCTION

Garden egg plants are fruit vegetables with economic and nutritional values (Naeem and Ugur, 2019). The fruits of garden egg plants have various shapes, such as oval (chicken eggs), spear-shaped, round, long, or cylindrical, depending on the variety; and their colour may vary from white to green (Yang and Ojiewo, 2013). *Solanum spp*. is a fruit vegetable that belongs to genus Solanum in the family Solanaceae. Over 1,400 species of garden egg has been reported worldwide, particularly in the temperate and tropical zones (Pessarakli *et al*., 2003). Garden eggs are rich in vitamins (A, B, and C) and minerals (phosphorus, iron, and potassium). Its production in China is the highest accounting for more than 64.60% of global production, followed by India at 21.04% (FAO, 2023). The yield of garden eggs in

Nigeria ranges from 15 to 40 tons/ha, depending on the management practices and variety (Law-Ogbomo and Osaigbovo, 2018). In Nigeria, Ikeh and Akpan (2018) reported fruit yields of 25.86 and 26.80 t/ha under good management practices. However, the yield of garden egg in Nigeria is not reflected in world production profile due to the lack of sufficient production records by small-scale growers, who are the main producers. However, Ibe *et al*. (2022) observed that the productivity and economic viability of garden eggs are encouraging in Nigeria. (Nevertheless, the garden egg enterprise is constrained by limited available land with adequate fertility status necessary to sustain or enhance its yield. This is largely due to the continuous mining of nutrients, particularly phosphorus, from the soil during harvest (Nair *et al*., 2020),

Despite their economic importance, garden eggs are cultivated on low fertility soils, resulting in low yields. The inability to sufficiently reverse the soil's physical fragility and chemical degradation through natural means leads producers to use mineral fertilisers. The application of mineral fertilisers has profound impacts on crop growth and productivity. In addition, vegetable farmers often cultivate a given variety with populations that exceed optimal levels, leading to reduced plant size and lower productivity. Hence, the current production efforts cannot satisfy the increasing demand for vegetables in urban areas and for export. The limitation of poor soil fertility, which causes low agricultural yield, can be managed by adding organic or inorganic fertilisers, to the soil to provide essential plant nutrients.

The application of inorganic fertilisers containing nitrogen often leads to soil acidity, which can impact bacterial activity and population. This, in turn, results in less efficient nitrogen transformation in the soil (Gu, *et al*., 2021). In spite of this, for subsistence farmers in Nigeria, inorganic fertilisers remain the primary source of soil fertility, despite the introduction of organic and organomineral fertilisers. The availability of nutrients in the soil to improve crop yields impact on soil health (Kekong *et al*., 2010; Undie, *et al*., 2013). The most common fertilisers utilised by small-scale farmers include various grades of compound fertilizer, such as NPK variants without proper soil testing to determine the actual deficient nutrient, and this usually cause nutrient imbalance (Li *et al*., 2019). Most nutrient limitations recognized by farmers are related to nitrogen, while others which go largely unrecognized may pose greater threats. For instance, even after plants have received sufficient nitrogen nutrition, the limited availability of phosphorus in soils might act as a "limiting factor" for shoot and root growth in crops like garden egg (Okada *et al*., 2004; Grzebisz *et al*., 2024). Phosphorus is an essential plant nutrient crucial for plant development. It is essential for key plant functions such as photosynthesis, energy transfer, genetic information, nutrient movement within the plant, and the transformation of sugars and starches (Grzebisz *et al*., 2024). However, the visible effect of phosphorus deficiency in crops is associated with a decrease in leaf expansion or surface area and a reduction in the number of leaves (Usandivaras *et al*., 2018).

Various sources are available to supplement soil phosphorus deficiency, either through organic or inorganic means. However, the commonly adopted method is the inorganic source, through the application of single super phosphate (SSP). The SSP is a straight phosphatic fertiliser that contains 16-20% water-soluble P_2O_5 and other nutrients, such as sulfur (12%) and calcium (21%). The favourable response of crops to Single Super Phosphate (SSP) application has been reported (Kareem *et al*., 2020; Zhang *et al*., 2021; Parashar *et al*., 2020). Bar-Yosef et al. (2015) and Grzebisz *et al*. (2024) reported that a lack of a favourable response to SSP could lead to limitations in nitrogen availability for crop growth. Similarly, to prevent the masking effect of agroecological parameters, SSP should be evaluated within specific agro-climatic zones. Consequently, the recommendation for phosphorus (P) fertiliser varies for different crop species, ecological conditions, and the inherent soil phosphorus status (Kareem *et al*., 2020; Zhang *et al*., 2021; Parashar *et al*., 2020). The absence of soil testing programmes has resulted in the under- or over-application of phosphorus fertilisers, leading to the unhealthy soil condition known as "nutrient imbalance" and, consequently, poor crop performance (Grzebisz *et al*., 2024). This imbalance could affect the native soil microbes and alter their population dynamics (Dixit *et al*., 2024).

The ecological function of soil microorganisms is crucial for a better understanding of how fertiliser treatments impact soil microbial diversity and nutrient uptake, ultimately enhancing crop performance. The composition and dynamics of soil microbes vary with the availability and types of phosphorus in the soil. They are very relevant to the mineralization and immobilization of phosphorus in the soil. It is vital to examine the composition and dynamics of microbial populations affected by the application of SSP. The objectives of this study were to determine the effect of single super phosphate fertiliser application on the performance of *Solanum aethiopicum* gr gilo and to assess the variation in soil microbial population resulting from phosphorus fertiliser application.

MATERIALS AND METHODS

Experimental location: The experiment was conducted in 2022 and 2023 at the screenhouse and the Research field of the Department of Crop and Horticultural Sciences, University of Ibadan, Nigeria (7°27´N, 3°53´E, and 234 m above sea level for the screenhouse study and 7°27´N, 3°53´E and 234 m above sea level for the field experiment). The experimental site is located in the derived savannah zone with a bimodal rainfall pattern, as reported by Egbinola and Amobichukwu (2013).

Soil Analysis: Soil samples for the pot and field experiments were collected from the 0–15 cm layer using a soil auger before land preparation. Soil samples were air-dried and sieved (2.0 mm) for routine soil analysis to determine the chemical and physical properties, following the methods described by Carter and Gregorich (2007). The SSP fertiliser used was also analyzed to determine the amount of available phosphorus in the fertiliser according to Thiex (2016). The values of the soil's physical and chemical properties are presented in Table 1.

Treatments and Experimental Design

The treatments involved phosphorus fertiliser at application rates of 0, 15, 30, and 45 kg P_2O_5/ha. The source of phosphorus fertiliser was single super phosphate containing 18% P_2O_5. The pot experiment was laid out in a randomized complete block design, and the field study utilized a randomized complete block design as well. The pot and field experiments were replicated five and three times, respectively.

Determination of Soil Microbial Population

The determination of soil microbial populations for bacteria and fungi was conducted using the serial dilution method outlined by Ben-David and Davidson (2014). To isolate the appropriate microbial population, serial dilution was performed using a nutrient agar medium. One gram of each soil sample was dissolved in 10 ml of 1% saline. The serial dilution process involved transferring 1 ml of the soil suspension into 9 ml of saline to achieve a dilution of 10-1.

Table 1. Physical and chemical properties of the soil at the experimental site

Parameters	**Value**	**Critical value (Enwezor *et al*., 1989)**	**Remarks**
Total Nitrogen (%)	3.26	1-3	High
Organic Carbon (%)	1.98	2-5	Moderate
Available P (mg/kg)	14	10 – 40	Moderate
pH (water) 1: 2	6.7	6.5 - 8.5.	
Exchangeablebases (cmol/kg)			
Ca	1.5	6 – 12	Low
Mg	0.79	3 – 6	Low
K	0.46	2 – 4	Low
Na	0.33	0.5 - 1.5	
Basicmicro-elements (mg/kg)			
Fe	10.9	10 – 40	
Mn	97	5 – 30	
Cu	0.85	2 – 10	
Zn	1.11	5 – 20	
Soil textural class (%)			Sandy loam
Sand	79	50 – 70	
Silt	13	20 – 40	
Clay	8	10 – 30	

Nursery Planting

Seeds of the Bello variety of garden egg were sown in nursery trays filled with coco peat on February 11, 2022, and March 17, 2023 (both in the dry season), at the screen house of the Department of Crop and Horticultural Scieences, University of Ibadan, Ibadan, Nigeria. One seed was sown per hole in nursery trays and later transplanted into planting bags four weeks after sowing. Microfertiliser of 2 g of NPK disolved 100 mL of water was applied 1 mL/plant to the base of the seedlings about two weeks after planting. This was done to provide nutrients to the seedlings.

Planting Procedures

In the pot experiment, each polythene bag was filled with 10 kg of soil obtained from the experimental site, and the treatments were applied one week after transplanting. The planting bags were labelled according to the various treatments. The bags are spaced at 60 cm x 60 cm between and within rows. Daily watering was carried out because the weather was extremely dry during the entire growing season. All the experimental pots were subjected to the same management practices.

Transplanting was carried out in the field six weeks after sowing. The transplanting was done after the seedlings had been hardened by exposing them to sunlight for two weeks. Adequate watering was done before transplanting to facilitate the removal of the seedling. The seedlings were transplanted at a spacing of 60 cm inter-row × 60 cm intra-row (Gurung *et al*., 2018).

The data collected from the pot and field experiments included plant height (measured from the base of the plant to the tip with the aid of a ruler), number of leaves (counted visually), and leaf area, which was calculated using the Rivera *et al*. (2007) model for the egg plant cultivar: LA = 0.641(L × W), where LA represents leaf area, L is the length of the leaf from tip to base, and W is the breadth of the leaf. The length and width of leaves were measured using a ruler, and the leaf area was calculated. The yield parameters included the number of fruits per plant and the weight of fruits per plant, which were later extrapolated to per hectare.

The data collected were subjected to analysis of variance (ANOVA) using GenStat 10.3DE version. Significant differences were separated using the Least Significant Difference (LSD) at a 5% significance level.

RESULTS

Effect of single super phosphate application on plant height

The responses of garden egg to the application of single super phosphate (SSP) in the pot and field experiments are shown in Table 1. At 2, 4, and 6 Weeks After Transplanting (WAT), there was no significant variation in plant height between the SSP-treated plants and the control in both pot and field experiments. At 8 WAT, the application of SSP significantly improved the height of garden egg plants compared to the control in the pot experiment. In the field, no significant difference was observed between the SSP-treated plants and the control. However, the height of the garden egg increased with the application of SSP, reaching its maximum at 45 kg P_2O_5/ha. In the pot experiment, the heights of plants treated with SSP at 15 and 30 kg P_2O_5/ha were significantly higher than those of the control at 10 WAT. However, the heights of plants treated with 45 kg P_2O_5/ha were similar to those of the other treatments. On the field, the heights of the SSP-applied treatments were similar, but the treatment with 30 kg P_2O_5/ha had a significantly greater plant height compared to the control.

Table 2: Influence of single super phosphate application on the height (cm) of garden egg under pot and field conditions in Ibadan, Nigeria

Treatments	2 WAT	4 WAT	6 WAT	8 WAT	10 WAT
Pot experiment					
0 (Control)	14.67	27.00	48.17	57.17b	67.67b
15 kg P_2O_5/ha	13.15	34.83	54.83	64.17a	74.17a
30 kg P_2O_5/ha	15.07	30.67	54.50	64.33a	74.33a
45 kg P_2O_5/ha	15.92	30.33	55.83	64.67a	73.17ab
LSD	Ns	ns	ns	6.55	5.65
Field Experiment					
0 (Control)	6.67	15.67	35.25	38.96	48.92b
15 kg P_2O_5/ha	6.33	14.83	41.25	42.29	53.47ab
30 kg P_2O_5/ha	8.08	17.17	48.00	53.75	71.41a
45 kg P_2O_5/ha	9.00	20.00	51.00	57.71	69.92ab
LSD	ns	Ns	ns	ns	21.48

WAT = Weeks after transplanting

Influence of single super phosphate application on garden egg number of leaves

The increase in single super phosphate (SSP) application improved the number of leaves produced, with the highest values observed at 30 kg P_2O_5/ha at 2, 4, 6, 8, and 10 WAT. No significant differences were observed among the treatments and across the observation periods in the pot study. On the field, the number of leaves at 2 and 4 WAT was similar, and the treatment with 30 kg P_2O_5/ha had higher values compared to the other treatments. The application of 30 and 40 kg P_2O_5/ha significantly increased the number of leaves in the garden egg compared to the control at 6 WAT but had similar values to the 15 kg P_2O_5/ha treatment. A similar trend was observed at 8 WAT, but the values among the treatments did not differ significantly. At 10 WAT, the number of leaves observed for plants treated with 30 and 45 kg P_2O_5/ha was similar to those treated with 15 kg P_2O_5/ha but significantly different from the control.

Table 4: Influence of single super phosphate application on garden egg number of leaves per plant under pot and field conditions in Ibadan, Nigeria

Treatments	2 WAT	4 WAT	6 WAT	8 WAT	10 WAT
Pot experiment					
0 (Control)	6.17	10.00	21.33	31.83	38.17
15 kg P_2O_5/ha	5.67	9.00	18.50	32.00	38.33
30 kg P_2O_5/ha	5.83	9.83	21.83	33.67	38.33
45 kg P_2O_5/ha	5.33	8.67	19.83	31.33	37.67
LSD	ns	Ns	ns	ns	ns
Field experiment					
0 (Control)	3.25	7.25	14.13	24.50b	31.07
15 kg P_2O_5/ha	3.25	8.88	20.75	31.75ab	41.51
30 kg P_2O_5/ha	4.17	11.00	27.25	40.13ab	52.99
45 kg P_2O_5/ha	3.58	8.50	25.13	41.75a	50.82
LSD	ns	ns	ns	16.889	ns

WAT = Weeks after transplantin

Influence of single super phosphate application on the leaf area

The influence of SSP application on the leaf area of the garden egg is shown in Table 3. The SSP applied to garden egg plants had a similar effect on leaf area throughout the growth period. Significant differences in leaf area were only observed at 2 WAT with a significantly higher value at 15 kg P_2O_5/ha compared to the control. The values observed for the other WAT were not significantly different in the pot experiment. However, treatments with the application of 15, 30, 30, and 45 kg P_2O_5/ha had the highest leaf area at 4, 6, 8, and 10 WAT, respectively. On the field, the treatment with 30 kg P_2O_5/ha resulted in the highest leaf area at 2 and 4 WAT but no significant variation was observed among the treatments. At 6 WAT, the impact of applying 30 and 45 kg of P_2O_5/ha on the garden egg leaf area was comparable to the treatment with 15 kg of P_2O_5/ha, but it showed significantly higher values compared to the control. At 8 WAT garden egg leaf area had the highest value at 30 kg P_2O_5/ha level of application, but it was similar to the other treatments. Significantly higher leaf area values were observed with the applications of 30 and 45 kg P_2O_5/ha compared to the control, but they had similar values to the 15 kg P_2O_5/ha treatment.

The influence of SSP on yield components and yield of garden egg

In the pot experiment, the application of SSP had no significant influence on the number of fruits per plant produced, as indicated in Table 5. However, the treatment with 15 kg P_2O_5/ha had the highest number of fruits per plant, while the treatment with 30 kg P_2O_5/ha had the lowest number. The application of higher levels of SSP (30 and 45 kg P_2O_5/ha) resulted in significantly more fruit sets per plant compared to the lower level and control. The treatment with 30 kg P_2O_5/ha resulted in the highest fruit yield, which was significantly different from the other treatments. Additionally, the application of 45 kg P_2O_5/ha significantly improved the yield of garden egg fruit compared to the 15 kg P_2O_5/ha and control treatments, which showed similar results. While there were no significant differences in the dry shoot biomass among the treatment means, the highest and lowest values were observed in the 30 kg P_2O_5/ha and control treatments, respectively.

On the field, applying 30 and 45 kg P_2O_5/ha resulted in significant increases in the number of fruits per hectare compared to the control, but there were no significant differences among the application levels. However, there was a slight increase in fruit size with an increase in the level of application. The application of 30 and 45 kg P_2O_5/ha also significantly improved fruit yields compared to the control, while the yield observed at 15 kg P_2O_5/ha was similar. A yield increase of 14.82% was observed when applying 30 kg P_2O_5/ha compared to 15 kg P_2O_5/ha.

Table 3: Influence of single super phosphate application on the leaf area (cm^2) of garden egg under pot and field conditions in Ibadan, Nigeria

Treatments	2 WAT	4 WAT	6 WAT	8 WAT	10 WAT
Pot experiment					
0 (Control)	95.75b	318.00	444.67	506.17	429.33
15 kg P_2O_5/ha	106.93ab	423.90	535.50	640.33	404.00
30 kg P_2O_5/ha	132.33a	401.83	551.83	685.50	568.83
45 kg P_2O_5/ha	103.40ab	411.33	513.83	630.33	599.00
LSD	31.58	ns	ns	ns	ns
Field Experiment					
0 (Control)	65.00	95.50	283.00b	456.00	389.58b
15 kg P_2O_5/ha	52.25	130.00	353.75ab	468.25	469.00ab
30 kg P_2O_5/ha	113.00	234.50	459.00a	627.50	713.92a
45 kg P_2O_5/ha	89.75	202.75	467.00a	621.75	667.05a
LSD	ns	ns	130.86	ns	266.10

WAT = Weeks after transplanting

Table 5: The influence of single super phosphate on biomass and yield performances of garden egg under pot condition in Ibadan, Nigeria

Treatments	Number of fruits/plant	Number of fruits set/plant	Fruit weight/plant (g)	Dry shoot biomass (g)
Pot experiment				
0 (Control)	17.52	30.60b	39.52c	73.13
15 kg P_2O_5/ha	16.27	30.08b	50.27c	75.63
30 kg P_2O_5/ha	18.27	35.35a	80.02a	77.63
45 kg P_2O_5/ha	17.77	35.89a	61.27b	75.63
LSD	ns	3.67	10.89	Ns

Table 5: The influence of single super phosphate on the yield and yield components of garden egg under field condition

	Number of fruits/ha (kg)	Average size/fruit	Fruit weight/ha (kg)
Field experiment			
0 (Control)	216666.67b	21.99	4763.70b
15 kg P_2O_5/ha	412314.81ab	22.59	9313.80ab
30 kg P_2O_5/ha	463518.52a	23.07	10695.00a
45 kg P_2O_5/ha	496574.07a	24.64	12235.74a
LSD	230486.00	ns	5090.00

The influence of SSP fertiliser applications on soil bacteria colonies

The total bacteria count in the soil before planting was lower compared to the total bacteria count observed after planting for all levels of application (Figure 1). At an application rate of 30 kg P_2O_5/ha of SSP, the total bacterial colonies were significantly higher than at the other levels, except when SSP was applied at 15 kg P_2O_5/ha. There were, however, 42.7% more bacterial colonies at 30 kg P_2O_5/ha of SSP than at 15 kg P_2O_5/ha. There was no significant difference between the bacteria colonies observed at 45 kg P_2O_5/ha of SSP applied and the control. However, an increase of 17.1% in colonies was observed under the application of 45 kg P_2O_5/ha compared to the control.

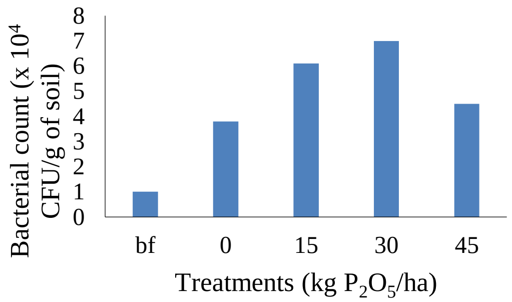

Figure 1: Total Soil Bacteria count as influenced by single superphosphate fertiliser applications and before transplanting in Ibadan, Nigeria. bf = Before transplanting

The influence of SSP fertiliser applications on soil fungal colonies

No significant variation was observed among the treatments for fungal colony assessment (Figure 2). The total microbial count of fungal colonies increased with the application of 15 kg P_2O_5/ha of Single Super Phosphate (SSP), with the highest increase observed at 30 kg P_2O_5/ha. Higher levels of SSP application (45 kg P_2O_5/ha) resulted in a reduction of soil fungal colonies in the soil. The application of 30 kg P_2O_5/ha resulted in a 40, 20 and 60% increase in fungal colonies compared to 15, 0 and 45 kg P_2O_5/ha of SSP, respectively. The fungal colonies observed at 45 kg P_2O_5/ha were similar to those observed before planting.

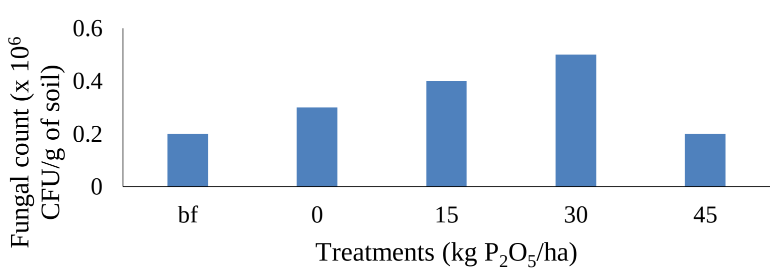

Figure 2: Total soil fungi count under different rates of single superphosphate fertiliser application and before transplanting in Ibadan Nigeria. bf = Before transplanting

DISCUSSION

The availability of plant nutrients in the soil affects the level of crop growth and development. The results of single super phosphate (SSP) fertiliser application on garden egg height indicated that the availability of phosphorus (P) nutrients in the soil was insufficient to support optimal garden egg height in both pot and field studies. The responses of the garden egg to the application of SSP in the pot and field experiments indicated a gradual increase in plant height for all the treatments, with no significant differences ($p<0.05$) at the early growth stage.

However. The significant increase in height from 8 WAT and 10 WAT for the pot and field studies, respectively, indicated a notable accumulation of nutrients leading to a pronounced difference in height between the SSP-applied treatments and the control. This finding is consistent with the report by Parashar *et al*. (2020) that the application of 60 kg of SSP significantly improved the plant height of Black Gram. Similarly, Kareem *et al*. (2020) reported that the application of 90 kg P_2O_5/ha of SSP improved tomato production. The contribution of P to crop height improvement is attributed to its influence as a major constituent of cell nucleus. Therefore, making P supply essential for cellular division and the development of meristematic tissues in plants. The division of cells at the apical portion of the plant leads to an increase in plant height.

Consequently, adequate uptake of P improve the plant rooting system and photosynthesis traits in certain plants, thus causing them to possess greater heights than plants with insufficient P uptake (Shukla *et al*., 2017; Yu *et al*., 2020; Lambers, 2022). Although the magnitude of the difference among the SSP-applied treatments was not significant, both the pot and field studies indicated that plants treated with 30 kg P_2O_5/ha exhibited the greatest increase in garden egg height compared to other application levels.

In the pot study, the gradual increase in the number of leaves for the treatments was similar, with no noticeable difference observed throughout the study. On the field, the treatments of 30 and 45 kg P_2O_5/ha resulted in a higher number of leaves between 6 and 10 WAT, with significance ($p<0.05$) observed at 8 WAT with the 45 kg P_2O_5/ha treatment. The increase in the number of leaves on garden egg plants substantiates the dramatic effect of P supply on leaf development in crops. Adequate application of phosphorus to crops enhances the rate of leaf appearance by 10% (Usandivaras *et al*., 2018). The more leaves there are available to actively intercept sunlight, the better the photosynthetic process and the accumulation of photosynthate by the crop for growth and development. The application levels of 30 and 45 kg P_2O_5/ha are considered to be more effective for improving the number of leaves produced by garden eggs. This finding corroborates the report by Shi *et al*. (2020) that a deficiency of P supply in the soil severely inhibits the growth and appearance of leaves in groundnuts. These unfavourable conditions were attributed to a significant reduction in photosynthesis.

The enhancement in phosphorus (P) nutrition in garden eggs resulted in increased leaf area of the plants compared to the control treatment during the observation period in both pot and field studies. This observation is substantiated by Khan *et al*. (2023), who reported that a deficiency of P nutrition in plants leads to a reduction in the rate of leaf expansion. Consequently, the plant's photosynthetic ability per unit leaf area is limited. According to Usandivaras *et al*. (2018), phosphorus deficiency could reduce leaf area expansion by 18%. The highest leaf areas at 8 and 10 WAT were observed in the garden egg with the applications of 30 and 45 kg P_2O_5/ha, respectively, in the pot. Likewise, on the field, the treatment with 30 kg P_2O_5/ha had the highest leaf area. The relative increase in leaf area observed at 30 kg P_2O_5/ha compared to the other levels of application signifies a more favourable condition for leaf growth and photosynthetic ability in garden eggs than the other levels. The relatively lower leaf area observed at the application level of 45 kg P_2O_5/ha could indicate unfavourable conditions associated with toxic P levels that inhibit leaf growth. A similar observation was reported by Shi *et al*. (2020) that the inadequate or toxic effect of P resulted in a significant reduction in photosynthesis in groundnuts.

The rate of crop growth ultimately affects the expected yield. The growth of crops is influenced by the availability of nutrients necessary to support the development of various growth parameters. Therefore, according to Liebig's Law of the Minimum, the most limiting factor in the soil determines the final crop yield (Tang and Riley, 2021). Under the cropping conditions in pot and field studies, the limiting nutrient was phosphorus (P), based on the critical nutrients required for garden eggs, as reported by Enwezor *et al*. (1989).

Consequently, the addition of phosphorus nutrients through Single Super Phosphate (SSP) fertiliser application could substantially improve crop growth and, subsequently, increase yield. Alongside the supply of P, the SSP fertiliser also contains calcium (18-20%) and sulfur (11-12%) in the form of calcium dihydrogen phosphate and calcium sulfate, respectively, which are equally essential for optimum plant development (Wu *et al*., 2018). The application of SSP fertiliser resulted in an increase in yield and yield components observed in both pot and field studies. The increase in the various yield parameters must have resulted from the impact of SSP o n plant height, number of leaves, leaf area, and aboveground biomass production.

The influence of P through the application of SSP on the growth and yield has been documented for crops such as maize, tomatoes, peppers, and soybeans (Wang *et al*., 2018; Usandivaras *et al*., 2018; Feng *et al*., 2021). They attributed the improvement in crop yields to an increase in leaf area development and enhanced leaf function, which promotes the production of shoot biomass, ultimately resulting in higher yields. These claims were supported by the results observed in both pot and field studies. There were increases in the growth of SSP-treated plants that resulted in higher garden egg yield, with the highest yield observed at 30 kg P_2O_5/ha. The reduction in growth and consequently, yield at the 45 kg P_2O_5/ha level in the pot experiment is supported by Shi *et al*. (2020) report. They reported that the limited or in certain cases, toxic availability of P in the soil is associated with a significant decrease in biomass production in groundnut.

However, in the field the higher yield observed for the 45 kg P_2O_5/ha over the 30 kg P_2O_5/ha could be the result of environmental factors that limit the availability of P to the plant root. These factors include soil organic matter, pH, texture, P-fixation, and soil moisture content (Khan *et al.*, 2023). However, these parameters were similar in both conditions, except for soil moisture content. In the field, soil moisture was not always consistent due to irregular rainfall, which could enhance phosphorus uptake by the plant roots. Therefore, plants respond better to the higher P application on the field compared to what was achievable in the pot experiment.

The findings of this study showed that the populations of both bacteria and fungi in the soil increased as fertiliser application rates increased, but declined in both microbe populations at the highest level of SSP fertiliser application. The increase in both the bacterial and fungal colonies could be attributed to the rise in organic carbon resulting from the expansion of the plant rooting system, which was facilitated by the application of SSP fertiliser. This, in turn, provided carbohydrates for the microbes. The addition of P to the soil improved garden egg growth by increasing the number of leaves and leaf area, thereby enhancing photosynthesis. This, in turn, promoted the growth of both aboveground and belowground biomasses (Feng *et al*., 2021; Yu *et al*., 2022; Wu *et al*., 2022). In Yu *et al*.'s (2022) study, the application of P fertiliser increased bacterial and fungal colonies by 11.1%, and 15.1%, respectively.

Consequently, the increase in belowground biomass improves soil organic carbon from dead plant roots, thereby encouraging microbial activities. This claim is supported by the responses observed at the 30 kg P_2O_5/ha of SSP compared to the other treatments in the pot experiment. Similarly, the lower bacterial and fungal colonies observed for the 15 and 45 kg P_2O_5/ha of SSP compared to the 30 kg P_2O_5/ha of SSP could be a result of the reduced growth response resulting from the fertiliser application. Wang *et al*. (2018) elucidated that a higher P application does not result in a significant increase in soil fungal and bacterial abundance. According to Wu *et al*. (2022), there is a positive correlation between soil microbial biomass and soil organic carbon. Therefore, the reduction in microbial colonies may not be solely associated with the availability of nutrients but also with the limitation of carbon for soil microbes (Morris *et al*., 2021). The treatments that showed a higher response from the SSP application had more microbial communities compared to those with a lower response.

CONCLUSION

The results from the pot and field studies revealed that the applications of SSP fertiliser increase the height, number of leaves, leaf area and the yield and yield parameters evaluated with highest improvement observed at 30 and 45 kg P_2O_5/ha of single super phosphate. The addition of single super phosphate fertiliser increased the number of bacteria colonies in the soil with the optimum at 30 kg P_2O_5/ha of single super phosphate. Similarly, the number of fungi colonies was highest at 30 kg P_2O_5/ha of single super phosphate, while higher level of application (45 kg P_2O_5/ha of single super phosphate) led to the depletion of fungal colonies after harvest. In conclusion, the application of 30 kg P_2O_5/ha of single super phosphate was recommended for optimum yield in garden egg and improvement of soil microbial population.

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