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Impact of inorganic and biofertilizers on soil biological modifications and rhizosphere dynamics in maize

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Abstract
The study evaluates the "Impact of inorganic and biofertilizers on soil characteristics and yield of maize in black soils" was conducted at Agricultural College Farm, Bapatla, during *rabi* of 2025 - 2026. The experiment was laid out in randomized block design with ten treatments and three replications using the treatments involving different levels of inorganics in combination with different biofertilizers. The treatments consist of T_1- absolute control; T_2 - 50% RDF +PSB; T_3- 50% RDF+ PSB + VAM; T_4- 50% RDF + PSB + VAM + KRB; T_5 - 75% RDF +PSB; T_6- 75% RDF + PSB + VAM; T_7- 75% RDF + PSB + VAM + KRB; T_8 - 100% RDF +PSB; T_9- 100% + PSB + VAM and T_{10}- 100% + PSB + VAM + KRB. Among the treatments, the combined application of 100% RDF + PSB + VAM + KRB (T_{10}) recorded the highest pH, EC, OC, CEC, available nutrient, microbial population enzyme activity and yield and lowest was recorded in T_1 (absolute control. The findings of the present study emphasize that the combined application of biofertilizers and inorganic fertilizers is essential for improving nutrient availability, enhancing microbial activity, maintaining soil fertility and soil health, and ultimately increasing crop yield.

Keywords: Maize, biofertilizers, inorganic fertilizers

Introduction
Maize (*Zea mays* L.) is one of the most important cereal crops cultivated across diverse agro-climatic regions of the world and is popularly known as the "Queen of Cereals" because of its high yield potential and multiple uses (Divya Vincent, 2025 and Navya Sree *et al.,* 2026) [3, 11]. It serves as a source of food, feed, fodder, and industrial raw material. In India, maize ranks third after rice and wheat and occupies about 120.91 lakh hectares with a production of 434.09 lakh tonnes and a productivity of 3590 kg ha^{-1} during 2024-25. In Andhra Pradesh, it is cultivated in about 3.3 lakh hectares with a production of 21.48 lakh tonnes and a productivity of 6510 kg ha^{-1} (Indiastat, 2024-25). Being a nutrient-exhaustive crop, maize requires adequate and balanced nutrition, particularly nitrogen, phosphorus, and potassium, for optimum growth, grain formation, and higher productivity.

Biofertilizers contains beneficial living microorganisms that improve nutrient availability through natural biological processes. Commonly used biofertilizers in maize cultivation include phosphate-solubilizing bacteria (PSB), vesicular arbuscular mycorrhiza (VAM), potassium-releasing bacteria (KRB), *Azospirillum*, and *Azotobacter*. These microorganisms fix atmospheric nitrogen, solubilize insoluble phosphorus, mobilize potassium, enhance root development, and stimulate beneficial microbial activity, thereby improving nutrient uptake and crop growth. The integrated use of biofertilizers with inorganic fertilizers enhances nutrient use efficiency, reduces nutrient losses, and minimizes dependence on chemical fertilizers. In addition to improving crop performance, integrated nutrient management positively influences soil physico-chemical, chemical, and biological properties by maintaining favourable soil pH, electrical conductivity (EC), organic carbon (OC), and cation exchange capacity (CEC), while increasing the availability of essential macro- and micronutrients. It also enhances soil microbial populations, enzyme activities, and nutrient cycling, thereby improving overall soil fertility and sustainability.

Black soils (Vertisols), which occupy a significant area under maize cultivation, possess high clay content, good water-holding capacity, and moderate to high inherent fertility. However, continuous cultivation and imbalanced fertilizer use often reduce nutrient availability and biological activity, affecting soil productivity. Therefore, adopting integrated nutrient management practices is essential for sustaining crop yield and preserving soil quality.

Materials and Methods

The experiment was conducted at Agricultural College Farm, Bapatla during *rabi,* 2025-2026. The soil of the experimental site was clay in texture, neutral in reaction (7.7), non-saline in nature (0.51 dS m^{-1}), medium in organic carbon (0.52%), low in available nitrogen (207 kg ha^{-1}), medium in available phosphorus (36 kg ha^{-1}) and high in available potassium (311 kg ha^{-1}). The secondary and all the micro-nutrients *viz.,* manganese, zinc and copper were well above their critical limits except zinc (0.52 mg kg^{-1}) which is below the critical limit and soil biological properties *viz;* bacterial population (23.1 x 10^6 CFU g^{-1} soil), fungal population (8.24 x 10^4 CFU g^{-1} soil), actinomycetes population (18.6 x 10^5CFU g^{-1} soil), dehydrogenase activity (32.1 µ g TPF g^{-1} soil 24 h^{-1}) and alkaline phosphatase activity (63.7 µ g PNP g^{-1} soil h^{-1}). The experiment was laid out in a randomized block design with ten treatments, replicated thrice. The treatments include control (0%RDF) (T_1), 50%RDF + PSB(T_2), 50%RDF + PSB +VAM (T_3), 50% RDF +PSB + VAM + KRB (T_4), 75% RDF+ PSB (T_5), 50% RDF + PSB+ VAM (T_6), 75% RDF +PSB +VAM + KRB (T_7), 100% RDF + PSB (T_8) and100%RDF+PSB + KRB(T_9), 100% RDF + PSB + VAM+ KRB (T_{10}). Initial soil samples were collected from the field randomly and made into composite samples, from the composite sample representative sample was taken by a quartering method. Plot- wise surface (0-15) soil samples were collected at knee- highand harvest stages of maize. The soil samples were air dried in the shade, ground and screened through a 2mm sieve and used for laboratory analysis. These soil samples were further estimated for soil pH by using glass electrode pH meter, EC by using conductivity bridge, organic carbon by using wet digestion method, CEC by ammonium acetate method, available nitrogen was estimated by the alkaline permanganate method by using a macro Kjeldahl distillation unit, available phosphorus in the soil samples was extracted with 0.5 M $NaHCO_3$ buffered at pH 8.5 and the phosphorus in the extract was estimated by the ascorbic acid method using a spectrophotometer at 660 nm, available potassium in the samples was extracted with neutral normal ammonium acetate and estimated with the help of a flame photometer, Available zinc, iron, manganese and copper in the soils were determined in DTPA extract, using atomic absorption spectrophotometer" and Bacterial count was determined by using serial dilution pour plate method, Fungi count was determined by using serial dilution pour plate method, Actinomycetes count was determined by using serial dilution pour plate method. Dehydrogenase activity in the soil sample was determined by using triphenyl tetrazolium chloride (TTC), Phosphatase activity was measured by estimating concentration of paranitrophenol (PNP) produced due to the hydrolysis of the substrate p-nitrophenol phosphate by phosphatase enzyme respectively.

Results and Discussion

Soil physico chemical properties

Soil reaction (pH)

The results of the present investigation revealed (Table 1) that the combined application of inorganic fertilizers and biofertilizers did not exert a significant influence on soil pH after harvest of maize. Although the differences were statistically non-significant, the lowest soil pH (7.4) was recorded with the application of 100% RDF + PSB + VAM + KRB (T_{10}), whereas the highest soil pH (7.69) was observed in the absolute control (T_1). The slight reduction in soil pH under T_{10} might be attributed to the production of organic acids and other acidic metabolites by phosphate-solubilizing bacteria (PSB) and potassium-releasing bacteria (KRB), along with enhanced root activity and microbial respiration, which release carbon dioxide and weak organic acids into the rhizosphere.

Electrical conductivity (dS m^{-1})

The results of the present investigation revealed (Table 1) that the application of inorganic fertilizers and biofertilizers did not exert any significant influence on the electrical conductivity (EC) of soil after harvest of maize. Although the differences were statistically non-significant, the highest EC (0.443 dS m^{-1}) was recorded with the application of 100% RDF + PSB + VAM + KRB (T_{10}), whereas the lowest EC (0.430 dS m^{-1}) was observed in the absolute control (T_1). The slight increase in EC under T_{10} might be attributed to the addition of inorganic fertilizers, which increased the concentration of soluble salts in the soil solution. The activity of PSB, VAM and KRB might have enhanced nutrient solubilization and mineralization, thereby increasing the concentration of soluble ions. However, the buffering capacity of the black soil and continuous uptake of nutrients by the crop maintained EC within a narrow range, resulting in non-significant differences among the treatments.

Organic Carbon (%)

The results of the present investigation revealed (Table 1) that the application of inorganic fertilizers and biofertilizers did not exert a significant influence on soil organic carbon (OC) after harvest of maize. Although the differences were statistically non-significant, the highest soil organic carbon content (0.58%) was recorded with the application of 100% RDF + PSB + VAM + KRB (T_{10}), whereas the lowest soil organic carbon content (0.44%) was observed in the absolute control (T_1). The relatively higher organic carbon content under T_{10} might be due to greater root biomass, root exudation and crop residue addition resulting from better crop growth under the combined application of inorganic fertilizers and biofertilizers. The enhanced microbial activity associated with PSB, VAM and KRB also might have contributed to the accumulation of organic matter in the soil. However, since the experiment was conducted for a single season, the changes in soil organic carbon were not sufficient to bring about significant differences among the treatments.

Cation exchange capacity (c mol$(p)^+kg^{-1}$)

The results of the present investigation revealed (Table 1) that the application of inorganic fertilizers and biofertilizers did not significantly influence the cation exchange capacity (CEC) of soil after harvest of maize. Although the differences among the treatments were statistically non-significant, the highest CEC (36.6 cmol(p^+) kg^{-1}) was recorded with the application of 100% RDF + PSB + VAM + KRB (T_{10}), whereas the lowest CEC (29.6 cmol(p^+) kg^{-1}) was observed in the absolute control (T_1). The relatively higher CEC under T_{10} might increased microbial activity and better nutrient cycling may also have contributed to the slight increase in CEC. However, cation exchange capacity is an inherent property of the soil and generally changes slowly. Since the experiment was conducted for only one cropping season, the treatments could not bring about significant changes in CEC.

Available Nutrients

Available Nitrogen (kgha^{-1})

The data pertaining to available Nitrogen in soil was found in Table 2 Available Nitrogen determined at knee high stage and harvest was found to be significantly influenced by the application of biofertilizers and inorganic fertilizers. The treatment T_{10}-100% RDF +PSB +VAM +KRB recorded significantly the highest available nitrogen 295 kg ha^{-1} in the soil at knee high stage whereas it was on par with T_9(100%RDF+PSB+VAM) (283kgha^{-1}) and T_7(75% RDF+PSB+VAM + KRB) (281 kg ha^{-1}) treatments and significantly superior to rest of the treatments. The lowest available nitrogen of 218 kg ha^{-1} in soil was recorded in absolute control (T_1). The treatment T_{10}-100% RDF + PSB + VAM + KRB recorded significantly the highest available nitrogen 282 kg ha^{-1} in the soil which was on par with T_9(100% RDF+PSB+VAM) (268kgha^{-1}) and T_7(75%RDF+PSB+VAM+ KRB) (260 kg ha^{-1}) treatments at harvest. The lowest available nitrogen of 197 kg ha^{-1} in soil was recorded in absolute control (T_1). The higher available nitrogen content observed in treatment T_{10} (100% RDF+ PSB + VAM + KRB) in both the stages of the soil might be due to the combined effect of recommended fertilizer dose and biofertilizers. Prashanth *et al.* (2021) [13] reported that the synergistic interaction among inorganic and biofertilizers, promoted efficient nutrient cycling, and reduced nitrogen losses, there by maintaining a higher amount of available nitrogen in the soil or might be due to the increase in the availability of nitrogen in the plots where biofertilizers were applied could also be attributed to the positive relationship between the added and native microorganisms in the soil that mineralized the organic matter. Reported by Gowtami *et al,* (2015) [6].

Available phosphorus (kg ha^{-1})

The data pertaining to available P in soil was present in Table 2 Available P in soil was determined at knee high and harvest stages were found to be significantly influenced by the application of inorganic and biofertilizers. The treatment T_{10}-100% RDF +PSB +VAM +KRB recorded significantly the highest available phosphorous was 67 kg ha^{-1} in the soil whereas it was on par with T9 (100% RDF+PSB+VAM) (64 kg ha^{-1}) and T_7(75%RDF+PSB+VAM+KRB) (62 kg ha^{-1}) treatments at knee high stage. The lowest available phosphorous (36 kg ha^{-1} in soil was recorded in absolute control (T_1). Amending soil with biofertilizers and inorganic fertilizers helps in enhancing the P concentration in solution through the mineralization of organic P and solubilization of natives soil P compounds by producing organic acids. The results were in close conformity with (Roy *et al.* 2021). The treatment T_{10}-100% RDF + PSB + VAM + KRB (T_{10}) recorded significantly the highest available phosphorous was 58 kg ha^{-1} in the soil. It was on par with T_9(100% RDF+PSB+VAM) (56.3 kg ha^{-1}) and T_7(75% RDF+PSB+VAM+KRB) (55 kg ha^{-1}) treatments and significantly superior to rest of the treatments at harvest. The lowest available P of 31 kg ha^{-1} in soil was recorded in absolute control (T_1). This might be due to the application of both inorganic fertilizers and biofertilizers, mainly which causes the solubilization and mineralization of inaccessible P that increases the P content in soil. Phosphorous availability declines as crop matures because of increase in drymatter content and plant uptake. These results were in consistent with the findings of Vijayalakshmi *et al*. (2020) [22].

Available Potassium (kg ha^{-1})

The data pertaining to available K in soil was presented in Table2. Available potassium determined at knee high stage and harvest was found to be significantly influenced by the application of inorganic and biofertilizers. The treatment T_{10}-100% RDF + PSB + VAM + KRB recorded the highest available potassium was 428 kg ha^{-1}in the soil, whereas it was on par with T_9(100% RDF+PSB+VAM) (419 kg ha^{-1}) and T_7(75%RDF+PSB+VAM+KRB) (412 kgha^{-1}) treatments at knee high stage. The lowest available potassium was 308 kg ha^{-1}in soil was recorded in absolute control (T_1). The higher availability of potassium in the soil during the early stages of crop growth might be due to the combined application of inorganic and biofertilizers, which enhanced nutrient availability through the mineralization of organic matter. Biofertilizers, particularly potassium-solubilizing bacteria and potassium releasing bacteria release organic acids that reduce potassium fixation and dissolve potassium-bearing minerals, thereby increasing the pool of available potassium in the soil. The treatment T_{10}-100% RDF + PSB + VAM + KRB recorded significantly the highest available potassium was 421 kg ha^{-1} in the soil whereas it was on par with T_9(100% RDF+PSB+VAM)(408 kg ha^{-1}) and T_7(75% RDF+PSB+VAM+KRB) (407 kg ha^{-1}) treatments. Significantly lowest available potassium was 298 kg ha^{-1} in soil was recorded in absolute control (T_1) at harvest. As the crop advanced towards maturity, the available potassium content declined due to increased nutrient uptake associated with greater drymatter production and continuous utilization by the growing plants reported by Vala*et al*., (2018) [21].

Available Calcium (cmol (p+) kg-1)

Available Ca at knee high and harvest stage of the crop was non-significantly influenced by inorganic and biofertilizers shown in Table 3. Maximum available Ca was 7.73 and 7.56 cmol (p^+) kg^{-1} obtained at knee high and harvest stages with the application 100% RDF+PSB+VAM+KRB (T_{10}) while the lowest was 6.33 and 6.17 at cmol (p^+) kg^{-1} noticed with control (T_1) treatment. The slightly higher available calcium content observed under T_{10} might be due to improved soil biological activity and the release of calcium from soil exchange sites through the action of organic acids and metabolites produced by biofertilizers. However, as black soils are inherently rich in calcium and possess a high buffering capacity, the treatments could not produce marked changes in available calcium, resulting in non-significant differences among the treatments.

Available Magnesium (cmol (p+) kg-1)

Combined application of biofertilizers and inorganic fertilizers exerted non-significant effect on available Mg at knee high and harvest stages of the crop given in Table 3. The highest available Mg of 5.24 and 5.08 cmol (p^+) kg^{-1} was obtained at knee high and harvest stages with the application 100%RDF+PSB+ VAM + KRB (T_{10}) while lowest was 4. 16 and 3.83 cmol (p^+) kg^{-1} was noticed with control. The relatively higher available magnesium content under T_{10} might be attributed to the improved nutrient cycling and enhanced microbial activity associated with the combined application of inorganic fertilizers and biofertilizers. The activity of PSB, VAM and KRB may have facilitated the release of magnesium from soil minerals into the soil solution, while improved root growth and greater root exudation helped maintain magnesium in the available form. However, magnesium availability in black soils is largely influenced by the mineral composition of the soil and changes gradually. Therefore, the variations among the treatments were small and remained statistically non-significant.

DTPA extractable Fe(mg kg^{-1})

DTPA extractable Fe at knee high and harvest stages of the crop was non-significantly influenced by biofertilizers and fertilizers presented in Table 4. Maximum DTPA extractable Fe was 10.5 and 9.83 mg kg^{-1} obtained at knee high and harvest stages with the application of 100% RDF+ PSB+ VAM+ KRB (T_{10}) while lowest was 7.13 and 6.97 mg kg^{-1} observed with absolute control (T_1). The results indicated that the application of inorganic fertilizers alone or in combination with biofertilizers did not cause any significant change in the available micronutrient status of the soil. However, treatments receiving a combined application of inorganic fertilizers and biofertilizers recorded slightly higher available micronutrient contents than the control. This may be attributed to enhanced microbial activity, which promoted mineralization and solubilization of native soil nutrients, and to the formation of chelated compounds that helped maintain micronutrients in available forms. The slight increase in available iron might also be due to a marginal reduction in soil pH resulting from microbial activity and the production of organic acids, which increased the solubility and availability of iron in the soil.

DTPA extractable Mn (mg kg^{-1})

DTPA extractable Mn at knee high and harvest stages of the crop was non- significantly influenced by biofertilizers and fertilizers presented in Table4. Maximum DTPA extractable Mn was 9.34 and 9.02 mg kg^{-1} obtained at knee high and harvest stages with the application of 100% RDF+ PSB+ VAM+ KRB (T_{10}) while the lowest was 7.13 and 6.97 mg kg^{-1} observed with absolute control (T_1). The combined application of inorganic fertilizers and biofertilizers did not significantly influence the available manganese content of the soil, although a slight increase was observed over the control. This might be due to enhanced microbial activity, which promoted the solubilization of native manganese and maintained it in plant-available forms. Manganese is more soluble under slightly acidic and reducing conditions, and a considerable proportion of soil Mn occurs in oxide and organic fractions, which are readily released into the soil solution. The available manganese content decreased with the advancement of crop growth, which may be attributed to the continuous uptake and removal of manganese by the maize crop.

DTPA extractable Cu (mg kg^{-1})

DTPA extractable Cu at knee high and harvest stages of the crop was non- significantly influenced by biofertilizers and fertilizers presented in Table 4. Maximum DTPA extractable Cu was 9.34 and 8.67 mgkg^{-1} was obtained at knee high and harvest stages with the application of 100% RDF + PSB + VAM + KRB (T_{10}) while the lowest was 5.93 and 5.71 mg kg^{-1} observed with absolute control (T_1). The slight increase in available copper with the combined application of inorganic fertilizers and biofertilizers might be attributed to the formation of stable soluble complexes that reduced copper fixation by soil constituents and enhanced its availability in the soil. Biofertilizer activity may also have facilitated the release of copper from native soil reserves. Copper has a strong affinity for amino groups, and soluble nitrogenous compounds such as amino acids are known to aid in the movement of copper within the soil-plant system, thereby improving its availability to plants.

DTPA extractable Zn (mg kg^{-1})

DTPA extractable Zn at knee high and harvest stages of the crop was non significantly influenced by biofertilizers and fertilizers presented in Table 4. Maximum DTPA extractable Zn was 9.34 and 8.67 mg kg^{-1} obtained at knee high and harvest stages with the application of 100% RDF + PSB + VAM + KRB (T_{10}) while the lowest was 5.93 and 5.71 mg kg^{-1} observed with absolute control(T_1). The available zinc content decreased with the advancement of crop growth from knee high to harvest stage. The highest available zinc content was recorded at the knee high stage, whereas the lowest was observed at harvest. This decline may be attributed to the continuous uptake and removal of zinc by the growing maize crop, resulting in depletion of available zinc from the soil. Similar findings were also reported by Subhalakshmi and Pratapkumar Reddy [19].

Biological properties

Bacterial population (X10^6 CFU g^{-1} soil).

The data pertaining to bacterial population in soil was represented in Table5. Soil bacteria population determined at knee high and harvest stages were found significantly influenced by biofertilizers and inorganic fertilizers. The highest bacterial population of 58.6× 10^6 CFU g^{-1} soil was recorded significantly with the treatment T_{10}(100% RDF + PSB+VAM+ KRB) whereas it was on par with the treatments T_9(100%RDF+PSB+VAM) (54.0×10^6CFUg^{-1}soil), T_7(75% RDF+ PSB + VAM+ KRB) (52.0×10^6 CFU g^{-1} soil) at knee high stage. The lowest was bacterial population was recorded with treatment T_1 (control) 26.0× 10^6 CFU g^{-1} soil. The combined application of inorganic and biofertilizers might improve nutrient availability and stimulate soil biological activity. Biofertilizers enhance the multiplication of beneficial microorganisms in the rhizosphere. Improved root growth resulted in greater release of root exudates, which served as a continuous source of carbon and energy for bacterial growth. The highest bacterial population of 27.0×10^6 CFU g^{-1} soil was recorded significantly in the treatment T_{10} (100% RDF + PSB+VAM+ KRB) and it was on par with the treatments T_9 (100% RDF+PSB+VAM) (26.0 ×10^6CFUg^{-1}soil), T_7(75% RDF+PSB+VAM+KRB) (25.0×10^6 CFU g^{-1} soil) at harvest. The lowest was bacterial population was recorded in T_1(control) treatment with 12.0 × 10^6 CFU g^{-1}soil. The presence of growth promoting substances in the root zone further supported microbial proliferation. Enhanced nutrient cycling under these treatments also created favourable conditions for bacterial multiplication. The bacterial population increased during the active growth period of the crop due to greater root activity and nutrient availability reported by Janardhan *et al*. (2022) [8]. A slight decline towards harvest might be attributed to reduced root exudation and depletion of readily available nutrients. In contrast, the control treatment recorded lowest bacterial population because the absence of fertilizer and biofertilizer application restricted microbial growth and activity in the soil reported by Chaudhari *et al*., (2020) [1].

Fungal population (X 10^4 CFU g^{-1}soil)

The data pertaining to fungal population in soil was represented in Table 5. Soil fungal population determined at knee high and harvest stages were found to be significantly influenced by biofertilizers and inorganic fertilizers. The highest fungal population 19.6× 10^4CFU g^{-1} soil at was recorded significantly with the treatment T_{10}(100% RDF+PSB+VAM+KRB) whereas it was found to be on par with T_9(100% RDF+ PSB+ VAM) (18.3×10^4 CFUg^{-1} soil), T_7(75%RDF+PSB+VAM+ KRB) (17.6×10^4 CFU g^{-1} soil) treatments at knee high stage. The lowest fungal population was recorded in T_1 (control) treatment with 9.33 ×10^4CFU g^{-1} soil. The highest fungal population 18.3 × 10^4 CFU g^{-1} soil was recorded significantly with the treatment T_{10}(100% RDF + PSB+VAM+ KRB) and it was found to be on par with T_9 (100% RDF+PSB+VAM) (17.0×10^4CFUg^{-1} soil), T_7 (75% RDF+ PSB+ VAM+ KRB) (16.3 ×10^4CFU g^{-1}soil) treatments at harvest. The lowest fungal population was recorded in T_1(control) treatment with 8.00 ×10^4CFU g^{-1} soil. The combined application of inorganic and biofertilizers significantly increased the fungal population at different stages of maize growth. The fungal population increased from the knee-high stage to the active growth stage of the crop and declined towards harvest. The increase in fungal population might be attributed to improved nutrient availability, particularly nitrogen, which supports fungal growth and multiplication. Biofertilizer application enhanced soil biological activity by creating favourable conditions for the growth of beneficial fungi. Greater root development and increased root exudation supplied sufficient carbon and energy sources for fungal proliferation. In addition, improved soil nutrient status under integrated nutrient management helped maintain a higher fungal population throughout the crop growth period. The decline at harvest might be due to reduced root exudation and depletion of readily available nutrients in the rhizosphere reported by of Mandal *et al*. (2017) [10]

Actinomycetes population (X10^5 CFU g^{-1}soil)

The data pertaining to actinomycetes population in soil was represented in Table5. Soilactinomycetes population determined at knee high and harvest stage was found to be significantly influenced by biofertilizers and inorganic fertilizers. The highest actinomycetes population 21.6 ×10^5CFU g^{-1}soil was recorded in the treatment T_{10}(100% RDF + PSB+VAM+ KRB) whereas it was on par with T_9 (100% RDF+PSB+VAM) (20.3×10^5CFUg^{-1}soil), T_7(75%RDF+PSB+VAM+KRB) (19.6×10^5CFU g^{-1}) treatments at knee high stages. The lowest Actinomycetes population was recorded in T_1 (control) with 12.6×10^5CFU g^{-1} soil. The highest actinomycetes population 18×10^5 CFU g^{-1} soil was recorded significantly with the treatment T_{10}(100% RDF + PSB+VAM+ KRB) while it was on par with T_9(100% RDF+PSB+VAM) (16.3×10^5CFUg^{-1} soil), T_7(75% RDF+PSB+VAM+KRB) (15.6 ×10^5CFU g^{-1}) treatments at harvest. The lowest Actinomycetes population was recorded in T_1 (control) treatment with 10.3×10^5CFU g^{-1} soil. Application of biofertilizers and inorganic fertilizers significantly increased the actinomycetes population in the soil during the crop growth period. The higher actinomycetes population might be attributed to the improved soil environment and enhanced nutrient availability under integrated nutrient management. The addition of biofertilizers promoted microbial activity by providing favourable conditions for the growth and multiplication of beneficial microorganisms. Increased root exudation and the availability of carbon compounds served as energy sources for actinomycetes. Sinha *et al*. (2019) [18] found that improved availability of secondary and micronutrients also supported microbial growth and development. As a result, treatments receiving both inorganic fertilizers and biofertilizers maintained a higher actinomycetes population compared to the control.

Enzyme activity

Dehydrogenase activity (µgTPF$g^{-1}$$hr^{-1}$)

Data related to dehydrogenase activity in soil at knee high and harvest stages are presented in Table 6. Dehydrogenase activity determined at knee high and harvest stages were found to be significantly influenced by combined application inorganic and biofertilizers. Among all the treatments, significantly the highest dehydrogenase activity was recorded in the treatment T_{10} (100% RDF + PSB+VAM+ KRB) with 70.2 and 44.1 µg TPF g^{-1} hr^{-1} in soil at knee high and harvest stages respectively whereas it was on par with the treatments T_9(100%RDF+PSB+VAM) (67.1 and 44.0 µg TPF g^{-1} hr^{-1} in soil) and T_7(75%RDF+ PSB+ VAM+ KRB) (65.7 and 43.5µg TPF g^{-1} hr^{-1} in soil) treatments. The lowest was recorded in T_1(absolute control) treatment with 38.5 and 37.8 µg TPF g^{-1} hr^{-1} in soil at both the stages of crop growth period. Significantly the highest dehydrogenase activity was observed in treatment T_{10} (100% RDF + PSB + VAM + KRB), which might be attributed to improved soil biological activity and organic matter status. The addition of biofertilizers enhanced microbial growth and respiration, thereby increasing the production of dehydrogenase enzymes in the soil. Improved nutrient availability and favourable rhizosphere environment further stimulated microbial proliferation and enzyme activity. The presence of sufficient organic carbon provided an energy source for soil microorganisms, resulting in increased enzymatic activity. In contrast, treatments receiving only inorganic fertilizers exhibited lower dehydrogenase activity due to the limited availability of organic substrates required for microbial growth and metabolism reported by Chopra *et al.* (2020) [2].

Alkaline Phosphatase activity (µg *p*-nitro phenol g^{-1} soil h^{-1})

The data pertaining to alkaline phosphatase activity in the soil at the knee-high and harvest stages are presented in Table 6and alkaline phosphatase activity in the soil at both the knee-high and harvest stages was significantly influenced by the combined application of inorganic and biofertilizers. Among all the treatments, significantly the highest alkaline phosphatase activity in soil was recorded in the treatment T_{10} (100% RDF + PSB + VAM + KRB) with 114 and 76 µg p-nitrophenol g^{-1} soil h^{-1} at the knee high and harvest stages respectively, whereas it was on par with the treatments T_9(100%RDF +PSB+VAM) (110 and 75 µg *p*-nitrophenol g^{-1} soil h^{-1}) and T_7 (75% RDF+ PSB+ VAM+ KRB) (108 and 74µg *p*-nitrophenolg^{-1}soilh^{-1}) treatments in soil at knee high and harvest stages respectively. The lowest was recorded in T_1 treatment (72.0 and 70.7 µg *p*-nitrophenol g^{-1} soil h^{-1}) in soil at both knee high and harvest stages of crop growth period. Alkaline phosphatase activity maximum was recorded at knee high stage and minimum at harvest. The higher enzyme activity during crop growth might be attributed to increased microbial activity and greater root exudation in the rhizosphere. Soil microorganisms continuously produce alkaline phosphatase to mineralize organic phosphorus into forms available for plant uptake. Kaur *et al*. (2017) [9] reported that root might have secreted organic acids and carbohydrates which stimulate higher soil enzyme activities. The application of PSB enhanced the microbial population, which in turn increased alkaline phosphatase activity in the soil. The combined use of inorganic phosphorus and biofertilizers created favourable conditions for microbial proliferation and enzyme activity. The decline in enzyme activity at harvest might be due to reduced root activity and depletion of readily available phosphorus in the soil. The soil enzyme activity was influenced by the type of crop, its age, the addition of fertilizers and the addition of manures.

Yield (kg ha^{-1})

Data pertaining to kernel and stover yield of the maize was assessed and the data was presented in Table7. The results indicated that the application of inorganic and biofertilizers showed a significant effect on kernel and stover yield.

Kernel yield (kg ha^{-1})

The maximum kernel yield of 6553 kg ha^{-1} was recorded significantly in treatment T_{10} with the application of 100%RDF + PSB + VAM + KRB which was at par with treatments T_9 (100% RDF + PSB + VAM) (6128 kg ha^{-1}) and T_7 (75% RDF + PSB + VAM + KRB) (6010 kg ha^{-1}), which was significantly superior over the rest of the treatments. The lowest kernel yield was observed in the treatment T_1 (absolute Control) with 3884 kg ha^{-1} which received no fertilizers during crop growth period. The combined application of inorganic and biofertilizers significantly enhanced kernal yield of maize. The application of biofertilizers improved the fertilizer use efficiency by increasing the availability of nutrients through enhanced microbial activity in the rhizosphere. These microorganisms promote mineralization of organic matter and facilitate the gradual release of essential nutrients and make them readily available to plants throughout the crop growth period, in addition to this biofertilizers such as VAM improve the root growth which enables the crop to explore a larger volume of soil for nutrient and water uptake. This results in better plant vigour and higher productivity. Gundlur *et al*. (2015) [7] and Tomar *et al*. (2017) [20] reported that the combined application of inorganic and biofertilizers enhanced the grain yield, due to the efficient nutrient utilization and improved yield attributes, which collectively contributed to increased productivity. The higher availability of N, P, and K in the soil due to balanced nutrient management showed a significant positive effect, which is in agreement with the findings of Nayak *et al.* (2020) [12].

Stover yield (kgha^{-1})

The highest stover yield of maize was recorded significantly in the treatment T_{10}(100%RDF + PSB + VAM + KRB) with 8662 kg ha^{-1} which was found to be at par with treatments T_9 (100%RDF+ PSB + VAM) (8367kgha^{-1}) and T_7(75% RDF + PSB + VAM + KRB) (8264 kg ha^{-1}), while the lowest stover yield of 5512 kg ha^{-1}was observed in the treatment T_1(absolute control). The increased stover yield might be due to higher nitrogen availability to the crop through combined application of inorganic and biofertilizers, which promoted the vigorus vegetative growth among the biofertilizers, PSB plays an important role in increasing phosphorus availability in the soil, as it enhances phosphorus uptake and improves several physiological and biochemical processes, including photosynthesis, energy transfer, carbohydrate metabolism, starch synthesis and improving overall crop productivity. Similar findings were reported by Tomar *et al*. (2017) [20].

Table 1: Effect of inorganic and biofertilizers on soil physico- chemical properties at harvest

Treatments	pH Soil water (1:2.5)	EC (dS m $^{-1}$)	OC (%)	CEC (cmol (P^+) kg^{-1})
T_1: CONTROL	7.67	0.43	0.44	29.6
T_2: 50% RDF + PSB	7.63	0.45	0.46	30.3
T_3: 50% RDF + PSB + VAM	7.62	0.47	0.47	30.6
T_4: 50% RDF + PSB + VAM + KRB	7.58	0.48	0.49	31.3
T_5: 75% RDF + PSB	7.57	0.51	0.51	31.6
T_6: 75% RDF + PSB + VAM	7.54	0.50	0.52	32.3
T_7: 75% RDF + PSB + VAM + KRB	7.52	0.51	0.54	33.6
T_8: 100% RDF + PSB	7.48	0.55	0.54	32.6
T_9: 100% RDF + PSB + VAM	7.47	0.52	0.56	35.0
T_{10}: 100% RDF + PSB + VAM + KRB	7.48	0.53	0.58	36.6
SEM	0.42	0.03	0.03	2.02
CD (0.05%)	NS	NS	NS	NS
CV (%)	9.5	9.8	10.0	10.7

Table 2: Effect of inorganic and biofertilizers on available nitrogen, phosphorus and potassium (kg ha^{-1}) in soil at knee high and harvest stages

Treatments	Available nitrogen (kg ha^{-1})		Available phosphorus (kg ha^{-1})		Available Potassium (kg ha^{-1})	
	Knee high	Harvest	Knee high	Harvest	Knee high	Harvest
T_1: Control	218	197	36.2	31.6	308	298
T_2:50%RDF+PSB	229	223	47.0	42.8	320	313
T_3:50%RDF+ PSB+ VAM	252	233	50.3	45.3	326	317
T_4:50%RDF+PSB+VAM+ KRB	261	240	53.7	48.1	331	322
T_5:75%RDF+PSB	267	246	56.0	50.4	363	358
T_6:75%RDF+ PSB+ VAM	272	253	58.8	51.5	374	364
T_7:75%RDF+PSB+VAM+ KRB	281	261	62.1	55.4	412	407
T_8:100%RDF+ PSB	276	255	59.1	53.1	398	391
T_9:100%RDF+ PSB+ VAM	284	268	64.6	56.3	419	408
T_{10}:100%RDF+PSB+VAM+ KRB	295	282	67.7	58.0	428	421
SEM (±)	14.7	11.3	3.13	2.72	28.2	28.5
CD (0.05%)	44	34	9.3	8.1	85	86
CV (%)	9.6	8.0	9.8	9.6	9.3	10.7

Table 3: Effect of inorganicand biofertilizers on available calcium and magnesium (cmol(P$^+$)kg^{-1}) in soil at knee high and harvest stages

Treatments	Available Calcium (cmol(P$^+$)kg^{-1})		Available Magnesium (cmol(P$^+$)kg^{-1})	
	Knee high	Harvest	Knee high	Harvest
T_1: CONTROL	6.33	6.17	4.16	3.83
T_2: 50% RDF + PSB	6.57	6.32	4.38	4.04
T_3: 50% RDF + PSB + VAM	6.71	6.67	4.43	4.11
T_4: 50% RDF + PSB + VAM + KRB	6.82	6.74	4.76	4.23
T_5: 75% RDF + PSB	6.96	6.86	4.81	4.34
T_6: 75% RDF + PSB + VAM	7.13	6.97	4.92	4.43
T_7: 75% RDF + PSB + VAM + KRB	7.34	7.22	5.08	4.71
T_8: 100% RDF + PSB	7.27	7.11	4.98	4.59
T_9: 100% RDF + PSB + VAM	7.51	7.38	5.17	4.93
T_{10}: 100% RDF + PSB + VAM + KRB	7.73	7.56	5.24	5.08
SEM (±)	0.34	0.30	0.29	0.30
CD (0.05%)	NS	NS	NS	NS
CV (%)	8.4	7.5	10.3	11.9

Table 4: Effect of inorganic and biofertilizers on available iron, manganese, copper and zinc (kg ha^{-1}) at knee high and harvest stages of maize

Treatments	Iron (kg ha^{-1})		Manganese (kg ha^{-1})		Copper (kg ha^{-1})		Zinc (kg ha^{-1})	
	Knee high	Harvest	Knee high	Harvest	Knee high	Harvest	Knee high	Harvest
T_1: CONTROL	7.13	6.97	6.64	5.97	5.93	5.71	1.36	1.29
T_2: 50% RDF + PSB	7.17	7.05	7.08	6.93	6.82	6.65	1.42	1.37
T_3: 50% RDF + PSB + VAM	7.69	7.48	7.34	7.21	7.26	6.76	1.48	1.42
T_4: 50% RDF + PSB + VAM + KRB	7.80	7.63	7.96	7.79	7.63	7.09	1.54	1.51
T_5: 75% RDF + PSB	8.16	7.71	8.17	7.92	7.74	7.14	1.62	1.58
T_6: 75% RDF + PSB + VAM	8.62	8.28	8.53	8.18	7.82	7.36	1.67	1.63
T_7: 75% RDF + PSB + VAM + KRB	9.67	9.44	9.04	8.89	8.65	8.06	1.73	1.71
T_8: 100% RDF + PSB	9.19	8.96	8.81	8.50	8.09	7.42	1.69	1.66
T_9: 100% RDF + PSB + VAM	9.93	9.64	9.17	8.97	9.23	8.41	1.84	1.75
T_{10}: 100% RDF + PSB + VAM + KRB	10.5	9.83	9.34	9.02	9.34	8.67	1.91	1.86
SEM (±)	0.72	0.70	0.64	0.64	0.67	0.58	0.13	0.12
CD (0.05%)	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	11.7	12.5	11.5	10.9	10.8	12.8	10.4	9.2

Table 5: Effect of inorganic and biofertilizers on bacterial, fungal and actinomycetes population in soil at knee high and harvest stages

Treatments	Bacterial population (X10^6 CFU g^{-1} soil) in soil		Fungal population (X10^4 CFU g^{-1} soil)		Actinomycetes population (X10^5 CFU g^{-1} soil) in soil	
	Knee high	Harvest	Knee high	Harvest	Knee high	Harvest
T_1: CONTROL	26.0	12.0	9.00	8.00	12.0	10.0
T_2: 50% RDF + PSB	29.0	16.0	10.0	9.00	13.0	11.0
T_3: 50% RDF + PSB + VAM	32.0	20.0	12.0	10.0	15.0	12.0
T_4: 50% RDF + PSB + VAM + KRB	37.0	22.0	13.0	11.0	15.0	13.0
T_5: 75% RDF + PSB	42.0	22.0	14.0	13.0	17.0	14.0
T_6: 75% RDF + PSB + VAM	45.0	24.0	16.0	14.0	17.0	14.0
T_7: 75% RDF + PSB + VAM + KRB	52.0	25.0	17.0	16.0	19.0	15.0
T_8: 100% RDF + PSB	49.0	26.0	16.0	15.0	18.0	15.0
T_9: 100% RDF + PSB + VAM	54.0	26.0	18.0	17.0	20.0	16.0
T_{10}: 100% RDF + PSB + VAM + KRB	58.0	27.0	19.0	18.0	21.0	18.0
SEM (±)	2.83	2.39	1.13	0.71	1.19	0.94
CD (0.05%)	8.5	7.2	3.4	2.2	3.4	2.8
CV (%)	11.6	9.8	10.4	9.5	9.7	10.8

Table 6: Effect of inorganic and biofertilizers on dehydrogenase and alkaline phosphatase activity in soil at knee high and harvest stages

Treatments	Dehydrogenase activity (µg TPF g^{-1} soil day^{-1})		Alkaline phosphatase activity (µg PNP $g^{-1}h^{-1}$)	
	Knee high	Harvest	Knee high	Harvest
T_1: CONTROL	38.5	37.8	72.0	70.7
T_2: 50% RDF + PSB	41.2	39.1	79.4	71
T_3: 50% RDF + PSB + VAM	43.1	40.2	83.0	72
T_4: 50% RDF + PSB + VAM + KRB	48.7	41.3	85.6	72
T_5: 75% RDF + PSB	54.5	42.3	92.7	73
T_6: 75% RDF + PSB + VAM	57.4	43.0	95.3	74
T_7: 75% RDF + PSB + VAM + KRB	65.7	43.5	108	74
T_8: 100% RDF + PSB	60.4	43.8	98.1	75
T_9: 100% RDF + PSB + VAM	67.1	44.0	110	75
T_{10}: 100% RDF + PSB + VAM + KRB	70.2	44.1	114	76
SEM (±)	3.56	2.10	5.77	1.70
CD (0.05%)	10.5	6.1	17.1	5.1
CV (%)	11.2	7.7	10.6	8.6

Table 7: Effect of inorganic and biofertilizers on kernel yield ($kgha^{-1}$) and stover yield (kg ha^{-1}) of maize

Treatments	Yield (kg ha^{-1})	
	Kernal	Stover
T_1: CONTROL	6884	8512
T_2: 50% RDF + PSB	7145	9012
T_3: 50% RDF + PSB + VAM	7650	9590
T_4: 50% RDF + PSB + VAM + KRB	8016	10016
T_5: 75% RDF + PSB	8362	10338
T_6: 75% RDF + PSB + VAM	8789	10813
T_7: 75% RDF + PSB + VAM + KRB	9010	11264
T_8: 100% RDF + PSB	8931	10929
T_9: 100% RDF + PSB + VAM	9128	11367
T_{10}: 100% RDF + PSB + VAM + KRB	9553	11662
SEm (±)	326	395
CD (0.05%)	978	1185
CV (%)	10.4	9.3

Conclusion

The present study demonstrated that the integrated application of biofertilizers and inorganic fertilizers significantly improved soil fertility, biological activity, and maize productivity under black soil conditions. The treatment 100% RDF + PSB + VAM + KRB (T_{10}) recorded the highest available N, P, and K, microbial population, enzyme activity, kernel yield, and stover yield, and was statistically on par with T_9 (100% RDF + PSB +VAM) and T_7 (75% RDF + PSB + VAM + KRB). Although soil physico-chemical properties (pH, EC, organic carbon, and CEC), secondary nutrients (Ca and Mg), and micronutrients were not significantly influenced, they showed a favourable numerical improvement under T_{10}. Overall, the combined use of biofertilizers with inorganic fertilizers enhanced nutrient availability, improved soil biological properties, maintained soil health, and increased maize yield.

References

1. Chaudhari LS, Mane SS, Jadhav KT. Influence of Integrated Nutrient Management on nutrition, quality and microbial population in soybean. International Journal of Chemical Studies. 2020;8(4):1201-1203.
2. Chopra R, Sharma M, Singh A, Mali H. Enzymatic activity and microflora population influenced by integrated nutrient management in haplustepts. Journal of the Indian Society of Soil Science. 2020;68(3):351-355.
3. Diya Vincent, Mrudhula KA, Sunil Kumar M. Effect of mulching on maize growth and yield under saline irrigation conditions. The Andhra Agricultural Journal. 2025;72(4):392-400.
4. Friedrich S, Platonova NP, Karavaiko GI, Stichel E, Glombitza F. Chemical and microbiological solubilization of silicates. Acta Biotechnologica. 2004;187-196.
5. Goutami N, Prasuna Rani P. Integrated nutrient management on content and uptake of nutrients by rice-fallow sorghum. International Journal of Agriculture Innovations and Research. 2016;4(5):2319-1473.
6. Goutami N, Rani PP, Pathy RL, Babu PR. Soil properties and biological activity as influenced by nutrient management in rice-fallow sorghum. International Journal of Agricultural Research, Innovation and Technology. 2015;5(1):10-14.
7. Gundlur SS, Patil PL, Rajkumara S, Ashoka P, Neelakantha JK. Influence of integrated nutrient management on yield and uptake of nutrients by maize and soil fertility under irrigated conditions in Vertisol. Karnataka Journal of Agricultural Sciences. 2015;28(2):172-175.
8. Janardhan S, Prasad PR, Venkata Subbaiah P, Venkateswarlu B, Ramesh D. Effect of Different Levels of Ferilizers in Combination with Biofertilizers on Biological Properties of Soil under Maize. International Journal of Plant & Soil Science. 2022;34(22):1407-1417.
9. Kaur H, Gosal SK, Walia SS. Synergistic effect of organic, inorganics and biofertilizers on soil microbial activities in rhizosperic soil of greenpea. Annual Research & Review in Biology. 2017;12(4):1-11.
10. Manda J, Kumari S, Chattopadhyaya N, Singh M. Integrated nutrient management boost the soil biological properties in rice rhizosphere. Journal of Crop and Weed. 2017;3(1):116-124.
11. Navya Sree B, Madhu Vani P, Latha M, Anny Mrudhula K. Effect of mulched drip irrigation with saline water on soil properties, yield, nutrient uptake and economics of maize. International Journal of Advanced Biochemistry Research. 2026;SP-10(7):480-487.
12. Nayak P, Reddy APK, Sunitha N, Naga KV. Performance of maize (*Zea mays* L.) under efficient nutrient management practices for sustainable crop productivity. International Journal of Chemical Studies. 2020;8(1):2454-2458.
13. Prashanth B, Hemalatha S, Naga Madhuri KV. Effect of Phosphorus Biofertilizers on soil microbial population

and growth characteristics of sweet corn (*Zea mays* L.). Journal of Pharmacognosy and Phytochemistry. 2021;9(3):631-634.

14. Rajrushi K, Prasunarani P, Anilkumar P, Prasad PRK, Madhuvani P. Influence of phosphorus levels, FYM and PSB on soil physical, physico-chemical and biological properties in Bt Cotton. The Andhra Agricultural Journal. 2014;61(2):339-343.
15. Ramakrishnaiah G, Vijaya T. Influence of VAM fungi, *Azotobacter* sp. and PSB on soil phosphatase activity and nutrients (N, P, K, Cu, Zn, Fe and Mn) status in the rhizosphere of *Stevia rebaudiana* plants. American Journal of Plant Sciences. 2013;4:1443-1447.
16. Richardson AE. Prospects for using soil microorganisms to improve the acquisition of phosphorus by plants. Australian Journal of Plant Physiology. 2001;28:897-906.
17. Roy MD, Sarkar GK, Das I, Karmakar R, Saha T. Integrated use of inorganic, biological and organic manures on rice productivity, nitrogen uptake and soil health in gangetic Alluvial soils of West Bengal. Journal of Indian Society of Soil Science. 2017;65(1):72-79.
18. Sinha SK, Prasad V, Prasad RK. Integrated effect of organic manure and *Azotobacter* with inorganic fertilizer on soil properties, yield and quality of sugarcane plant-ratoon system under calcareous soil. Journal of Pharmacognosy and Phytochemistry. 2019;5:321-326.
19. Subhalakshmi C, Pratap kumar reddy APK. Soil available nutrient status as influenced by organic sources and fertilizer levels in hybrid rice. International Journal of Science and Nature. 2017;8(1):40-43.
20. Tomar SS, Singh A, Sharma R, Naresh RK, Vineet K, Tyagi S, *et al*. Effect of integrated nutrient management for sustainable production system of maize (*Zea mays* L.) in Indo-Gangetic Plain Zone of India. International Journal of Chemical Studies. 2017;5(2):310-316.
21. Vala FG, Vaghasia PM, Zala KP, Akhata N. Response of integrated nutrient management on nutrient uptake, economics and nutrient status of soil in bold seeded summer groundnut. International Journal of Current Microbiology and Applied Sciences. 2018;7(01):174-180.
22. Vijayalakshmi V, Pradeep S, Manjunatha H, Krishna V, Jyothi V. The impact of nitrogen fixers and phosphate solubilizing microbes on sorghum (*Sorghum bicolor*) yield. Current Biotechnology. 2020;9:198-208.
23. Wani PA, Khan MS, Zaidi A. Effect of metal tolerant plant growth promoting *Bradyrhizobium* sp. on growth, symbiosis, seed yield and metal uptake by greengram plants. Chemosphere. 2007;70:36-45.