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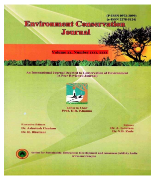

Response of maize to the combined application of innovative organic and inorganic sources of nutrients in an acid *Alfisol* of lower Himalayas

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ABSTRACT

Maize (*Zea mays* L.) is a high-yielding crop with remarkable productivity potential. However, realizing this potential heavily relies on efficient nutrient management. To optimize maize growth and yield, it is crucial to employ appropriate combinations of organic and inorganic sources of nutrients. Thus, the combined application of nutrients in an integrated manner consistently ensures higher and more stable crop yields. In the *Kharif* season of 2019, a field experiment was conducted at the Soil Science Experimental Farm of CSK HPKV, Palampur, focusing on the impact of combining organic and inorganic sources of nutrients on maize hybrid. The experiment was performed in accordance with a randomized block design, with ten different treatments replicated three times. The findings revealed that the maize crop responded significantly to various nutrient sources. Among the treatments tested, the combined application of Sagarika (both soil and foliar) along with water soluble fertilizers (18:18:18) and 75% NPK resulted in the highest grain (5.7 t/ha) and stover yields (8.8 t/ha) of maize. Additionally, this treatment exhibited superior results in terms of cob length (17.90 cm), cob diameter (4.31 cm), number of grains per cob (470), and test weight (32.77 g), surpassing all other treatments. In contrast, the lowest values (16.07 cm, 4.24 cm, 378 and 27.96 g for cob length, cob diameter, number of grains per cob, and test weight, respectively) were observed with the application of 75% NPK alone. Furthermore, optimizing nutrient doses through synergistic integration of organic and inorganic sources also improved the leaf nutrient status as well as the total nutrient uptake of a crop.

Introduction

Maize (*Zea mays* L.) is a globally significant crop and is the third most important crop in India, following rice and wheat. From temperate hill zones to semiarid deserts, it is cultivated in a wide range of production environments; hence, it is called the Queen of Cereals. Beyond its use as a human food and fodder, maize serves as a raw material for numerous food processing industries. Presently, in India, it is cultivated across an area of 9.20 million hectares, producing approximately 27.80 million metric tonnes annually, with a productivity of 29.65 quintals per hectare (Directorate of Economics and Statistics, 2020). Despite being primarily rainfed, maize contributes approximately 9% to the national food basket. Over the years, the state of Himachal Pradesh has undergone a remarkable transformation in maize production. The output, which once accounted for a mere 0.0673 million metric tonnes during the 1951-1952 period, has now surged impressively to 0.711 million metric tonnes by the fiscal year 2019-2020. This growth has been accompanied by an increase in productivity of 25.32 quintals per hectare (Directorate of Economics and Statistics, 2019).

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The post-green revolution era witnessed stagnation in crop yields, which urged the adoption of a sustainable production system that not only fed the ever-increasing population but also alleviated the deleterious effects of chemical intensive farming. Undoubtedly, higher doses of inorganic fertilizer have been proven to be effective at boosting short-term maize yields, but their excessive use has adverse impacts on soil health and productivity in the long run. To address these challenges, integrated nutrient management has emerged as a crucial approach for sustaining maize productivity (Wailare and Kesarwani, 2017). Maize is an exhaustive crop, and its nutrient requirements cannot be met through native nutrient reserves; hence, the crop needs to be judiciously fertilized with the combined application of organic and inorganic sources of nutrients (Ramalakshmi *et al*., 2012). Scientists are increasingly advocating for a novel approach to optimize nutrients in field crops by integrating innovative organic products such as biostimulants, biofertilizers, and water soluble fertilizers with conventional nutrient management techniques. Biostimulants are currently recognized as a new category of products in the “Fertilizer (Inorganic, Organic or Mixed) (Control) Amendment Order 2021” on February 23, 2021. These refer to substances, microorganisms or a combination of both (other than fertilizers and pesticides) whose primary function when applied to plants, seeds or the rhizosphere is to stimulate physiological processes in plants and to enhance nutrient uptake, growth, yield, nutritional efficiency, crop quality and tolerance to stress, regardless of nutrient content. Anticipated figures suggest that seaweed extracts are poised to capture more than 33% of the worldwide biostimulant market, projecting a value of 894 million Euros by the year 2022 (Eef *et al*., 2018). Seaweed-based biostimulants have long been recognized for their soil conditioning properties and their ability to serve as a source of organic matter in agriculture (Blunden and Gordon, 1986). The increasing popularity of seaweed derivatives can be attributed to their promising potential within the realm of organic and sustainable agriculture. They offer an avenue to curtail excessive reliance on chemical fertilizers while also improving plant nutrient uptake (Singh *et al*., 2016). The utilization of biostimulants derived from seaweed has demonstrated positive outcomes with respect to soil enzymatic activity and the composition of soil bacterial communities that enhance crop growth, even under drought conditions (Trivedi *et al*., 2021). Another promising strategy involves the use of biofertilizers in the form of consortia that contain cultures of dormant cells of effective strains of N-fixing, P-solubilizing and K-solubilizing bacteria (Fasusi *et al*., 2021). The NPK consortia (biofertilizer) is a liquid microbial blend of *Rhizobium*, *Azotobacter*, *Acetobacter*, and P-solubilizing and K-mobilizing bacteria. This consortium significantly boosts the uptake of essential NPK nutrients, leading to a substantial increase in crop yields (Pindi and Satyanarayana, 2012). Additionally, foliar sprays of water soluble fertilizers before the flowering stage have not only been shown to be effective at enhancing crop yields but also to be successful at preventing nutrient deficiencies during the critical crop growth stage (Manasa *et al*., 2015). Therefore, there is a greater scope of integrated nutrient management with innovative nutrient sources such as biostimulants, biofertilizers, and water soluble fertilizers for enhancing the productivity of crops.

Material and Methods

Experimental site:
The experiment was conducted during *Kharif* 2019 at the experimental farm of Soil Science, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, in the Kangra district of Himachal Pradesh. The site lies at an altitude of 1290 m above mean sea level and is within latitude 32° 09ʾ95” N and longitude 76° 55’03” E.

Soil characteristics:
Taxonomically, the soils of the experimental farm belong to the deep, acid, fine-silty, mixed, thermic family of *Typic Hapludalfs*. These are characterized by the presence of Ap, B, Bt1, Bt2 and Bt3 horizons. However, initially, the soils under study were acidic, with a pH of 5.6; a silty clay loam texture; a medium organic carbon content; an available nitrogen, phosphorus, and potassium status; and sufficient secondary and micronutrient cations.

Treatment details

The field experiment was carried out in a randomized block design with ten different treatments replicated three times, viz. T_1: 100% NPK, T_2: 75% NPK, T_3: 75% NPK+ two sprays of 0.25% Sagarika, T_4: 75% NPK+ 25 kg/ha Sagarika granules at sowing, T_5: 75% NPK+ two sprays of 2% Water soluble fertilizer (18:18:18), T_6: 75% NPK+ seed treatment with NPK Consortia @5 ml/kg of seeds, T_7: 75% NPK+ two sprays of 0.25% Sagarika + 25 kg/ha Sagarika granules at sowing, T_8: 75% NPK+ two sprays of 0.25% Sagarika + two sprays of 2% Water soluble fertilizer (18:18:18), T_9: 75% NPK+ 25 kg/ha Sagarika granules at sowing + two sprays of 0.25% Sagarika + two sprays of 2% Water soluble fertilizer (18:18:18) and T_{10}: 50% NPK + seed treatment with NPK Consortia @5 ml/kg of seeds + two sprays of 0.25% Sagarika + 25 kg/ha Sagarika granules

Field experimentation and operations

The chosen test crop was the Kanchan Gold hybrid of maize, which was planted on June 30th, 2019, at a rate of 20 kg/ha. FYM@10 t/ha was applied to all the experimental plots three days before crop sowing. For nutrient application, the recommended state-level NPK application rate was 120:60:40 kg/ha. Half of the nitrogen and the full doses of P_2O_5 and K_2O were applied as basal doses during planting. The remaining nitrogen was split into two equal portions and applied during the high-knee and tasseling stages of the maize plants. The inorganic sources of nutrients were DAP, urea and maize of Potash in solid form and water soluble fertilizer (18:18:18) in liquid form. The organic sources used were NPK consortia, a biofertilizer, and Sagarika (granular and liquid form), which is derived from red and brown marine algae and serves as a metabolic bioenhancer that acts as a biostimulant. Sagarika, NPK consortia and water soluble fertilizer (18:18:18) were procured from the Indian Farmers Fertilizer Cooperative Limited (IFFCO), a multistate cooperative society. For the seed treatment, the seeds were mixed uniformly with liquid NPK consortia just two hours before sowing. Foliar sprays of Sagarika and water soluble fertilizer were applied at the high knee and tasseling stages of maize. The maize crop was grown until it reached physiological maturity and harvested on October 28th, 2019.

Field studies

To record yield-related characteristics, five healthy plants were randomly selected and tagged in each plot. With the help of a scale, the lengths of five representative cobs were measured in centimeters, and the mean values were calculated. The diameter of the above five randomly selected cobs was measured with the help of a Vernier caliper from the base, center and top. To obtain the average cob yield, the mean value was multiplied by the value of π (3.14). The number of grains was counted from five randomly selected cobs from each plot, and the mean values were calculated. One hundred grains from five representative selected cobs from each plot were weighed in grams. After harvesting, the cobs were dehusked from each plot, air-dried, shelled and weighed. The grain yield per plot was recorded and expressed as t/ha. After the cobs were picked, the remaining plant material, i.e., stalks, was sun-dried and weighed to determine the stover yield in t/ha on a dry weight basis.

Laboratory studies

To assess nutrient status during the critical growth stage of maize, i.e., the pretasseling stage, flag leaves of maize were collected from each plot and then processed and analyzed for N, P, K, Ca, Mg, S, Cu, Fe, Mn, and Zn contents by adopting the standard protocols Jackson (1973); Black (1965); Chesnin and Yein (1950). The optimum range of nutrients for depicting their sufficiency or deficiency in the flag leaves of maize is given in Table 1. After crop harvest, representative grain and stover samples from each plot were air-dried and subsequently placed in a hot air oven at 60-70°C for 7 to 8 hours. The oven-dried grain and stover samples were then processed and analyzed for total nutrient contents as per standard procedures. The nutrient uptake was then computed by multiplying the % concentration of a particular nutrient by the grain and stover yields (q/ha) on a dry weight basis. The accumulation of nutrients derived from both grains and stover was combined to calculate the total quantity of nutrients extracted by the crop. This total uptake was determined as follows:

Total Uptake = Nutrient Uptake from Stover + Nutrient Uptake from Grains

Table 1: Optimum range of essential nutrients at the pretasseling leaf stage of maize according to Jaiswal (2003) and Campbell (2013)

Macronutrients					
N	**P**	**K**	**Ca**	**Mg**	**S**
2.8-4.0%	0.25-0.5%	1.8-3.0%	0.25-0.80%	0.15-0.6%	0.15-0.6%
Micronutrients					
Cu	**Fe**	**Mn**	**Zn**		
5-25 ppm	30-250 ppm	15-150 ppm	20-70 ppm		

Results and Discussion

Yield attributes:

Generally, all yield attributes are influenced by the integration of both organic and inorganic sources of nutrients. The maximum and minimum values of these attributes were recorded in T_9 (75% NPK + foliar spray of Sagarika + soil application of Sagarika + foliar spray of water soluble fertilizer) and T_2 (75% NPK), respectively. When comparing T_2 (75% NPK) with the other treatments, it was observed that the combination of Sagarika, water soluble fertilizer and NPK alone or in combination had a significant and positive effect on all the attributes except the cob diameter (Table 2). The effects on 100-grain weight were comparatively more pronounced. However, the effects of these treatments on the cob length and number of grains were less prominent. The increase in yield attributes with the combined application of organic and inorganic sources along with FYM could be due to rapid mineralization of organic sources resulting in a balanced supply of all essential nutrients. However, a prominent increase was observed in the treatments that received foliar sprays. Foliar feeding helps in supplying essential nutrients in critical stages of crop growth, thereby maximizing nutrient utilization (Fageria *et al.*, 2009). Moreover, Sagarika, as a biostimulant, enhanced the availability of nutrients due to its direct impact on the improvement of the root system, which could be influenced by the presence of growth regulators (e.g., auxins, cytokinins and gibberellins), amino acids and mineral nutrients that positively affect plant growth (Saucedo *et al.*, 2015). Similar results were reported by Basavaraja *et al*. (2018), where foliar application of seaweed sap at a 15% concentration along with 100% RDF significantly improved the yield attributes of maize.

Productivity:

All the treatments had a profound influence on the grain yield of maize, which ranged from 4.3 t/ha to 5.7 t/ha (Table 2). A significantly greater grain yield (5.7 t/ha) was recorded with the application of 75% NPK + foliar spray of Sagarika + soil application of Sagarika + foliar spray of water soluble fertilizer (T_9). When comparing the treatments that received 100% NPK (T_1) with the treatments that received 75% NPK + foliar spray of water soluble fertilizers (T_5) and 75% NPK + foliar spray of Sagarika + soil application of Sagarika (T_7), a significantly greater grain yield (5.2 t/ha) was registered with 100% NPK and was found to be on par with the later treatments, with 5.1 t/ha and 5.0 t/ha grain yields, respectively. However, the lowest grain yield was recorded with the application of 75% NPK (T_2), which was significantly lower than that of all the other treatments. The data clearly revealed a parallel trend in stover yield, with a maximum stover yield of 8.8 t/ha in T_9 (75% NPK + foliar spray of Sagarika + soil application of Sagarika + foliar spray of water soluble fertilizer) and a minimum of 7.2 t/ha in T_2 (75% NPK). The increased yield with the application of Sagarika and water soluble fertilizer might be ascribed to the synchronized release of plant nutrients throughout the crop growth period. The presence of phytohormones in seaweed formulations might increase cell division, cell wall expansion, meristematic activity, and root volume and proliferation, which leads to the distribution of photosynthates from vegetative parts to developing

Table 3: Effect of different treatments on the productivity and yield attributes of maize

Treatments	Yield (t/ha)		Cob Length (cm)	Cob diameter (cm)	Test weight (g)	Grains/cob
	Grain	Stover				
T_1	5.2 ± 0.12^{c}	8.1 ± 0.10^{c}	17.53 ± 0.28^{ab}	4.24^{NS}	30.81 ± 0.12^{c}	455 ± 6.93^{a}
T_2	4.3 ± 0.05^{g}	7.2 ± 0.16^{g}	16.07 ± 0.17^{c}	4.24^{NS}	27.96 ± 0.15^{f}	378 ± 10.97^{b}
T_3	4.8 ± 0.08^{de}	7.7 ± 0.04^{de}	17.53 ± 0.14^{ab}	4.26^{NS}	29.08 ± 0.18^{e}	456 ± 4.48^{a}
T_4	4.7 ± 0.02^{ef}	7.6 ± 0.07^{ef}	17.50 ± 0.11^{ab}	4.28^{NS}	28.92 ± 0.11^{e}	460 ± 3.05^{a}
T_5	5.1 ± 0.09^{c}	8.0 ± 0.15^{cd}	17.50 ± 0.11^{ab}	4.26^{NS}	30.11 ± 0.18^{d}	445 ± 8.76^{a}
T_6	4.5 ± 0.06^{f}	7.4 ± 0.06^{fg}	16.50 ± 0.15^{c}	4.26^{NS}	28.07 ± 0.13^{f}	445 ± 9.76^{a}
T_7	5.0 ± 0.11^{cd}	7.9 ± 0.13^{cd}	17.73 ± 0.08^{a}	4.28^{NS}	30.17 ± 0.18^{d}	449 ± 6.96^{a}
T_8	5.4 ± 0.04^{b}	8.5 ± 0.06^{b}	17.80 ± 0.05^{a}	4.28^{NS}	31.75 ± 0.17^{b}	460 ± 14.11^{a}
T_9	5.7 ± 0.07^{a}	8.8 ± 0.10^{a}	17.90 ± 0.05^{a}	4.31^{NS}	32.77 ± 0.21^{a}	470 ± 12.73^{a}
T_{10}	4.7 ± 0.05^{ef}	7.5 ± 0.10^{ef}	17.17 ± 0.12^{b}	4.28^{NS}	28.86 ± 0.21^{e}	450 ± 9.13^{a}

grains, ultimately resulting in the superior quality of agricultural products (Crouch and Staden, 1993; Reitz and Trumble, 1996). Kalaivany *et al*. (2019) also reported that foliar application of seaweed extracts improved the growth and yield of cowpea compared to those of the control. On the other hand, foliar nutrition through water-soluble fertilizers increased dry matter production, probably due to the high accumulation of NPK, which improved yield components and ultimately yield. Where soil application of 50% of the recommended dose of nitrogen, along with 50% of its foliar spray and the full recommended dose of phosphorus and potassium using a water-soluble fertilizer, followed by foliar application of 0.1% humic acid resulted in a notably increased ragi yield compared to other treatments. Nirere *et al*. (2019) reported positive outcomes of foliar feeding methods utilizing water-soluble fertilizers rich in plant nutrients in maize, where significantly greater grain and stover yields were recorded with 100% RDF (150:75:40 kg NPK/ha) + 2 sprays of water-soluble fertilizer (19:19:19) @ 0.5% at the knee height and tasseling stage than in the control.

Nutrient status of leaves at the pretasseling stage: The combination of Sagarika, water soluble fertilizers, and mineral fertilizers has emerged as a promising strategy for improving the nutrient content of maize plants. When comparing the nutrient status of leaves at the pretasseling stage with standard rating values for assessing nutritional status (Table 1), it was observed that the leaf N, P and K status was below the sufficient range in all treatments, whereas the secondary nutrient and micronutrient cation levels were within a sufficient range. However, both the macro- and micronutrient contents of leaves were relatively greater in the treatments with foliar sprays of Sagarika and water soluble fertilizer (Figure 1, 2 and 3). In the present investigation, the levels of nitrogen, phosphorus, and potassium in the flag leaves of maize during the pretasseling stage were below the established range. This called for top dressing or foliar application of these deficient nutrients. Usually, nitrogen, not phosphorus or potassium, is applied to crops at this critical stage; thus, foliar application of nutrients is beneficial for optimizing the nutrient requirements of crops, which subsequently enhances the overall growth and productivity of crops. Similar findings were reported by Stewart *et al*. (2021), who postulated that the foliar application of micronutrients during critical growth stages of maize was effective in enhancing the concentration of these micronutrients in leaf tissues. Importantly, none of the micronutrients fell below critical levels in the early-season leaf samples that were collected. These results underscore the importance of targeted nutrient supplementation at specific growth stages for optimizing maize growth and ensuring that essential nutrients are maintained at adequate levels throughout the early stages of crop development.

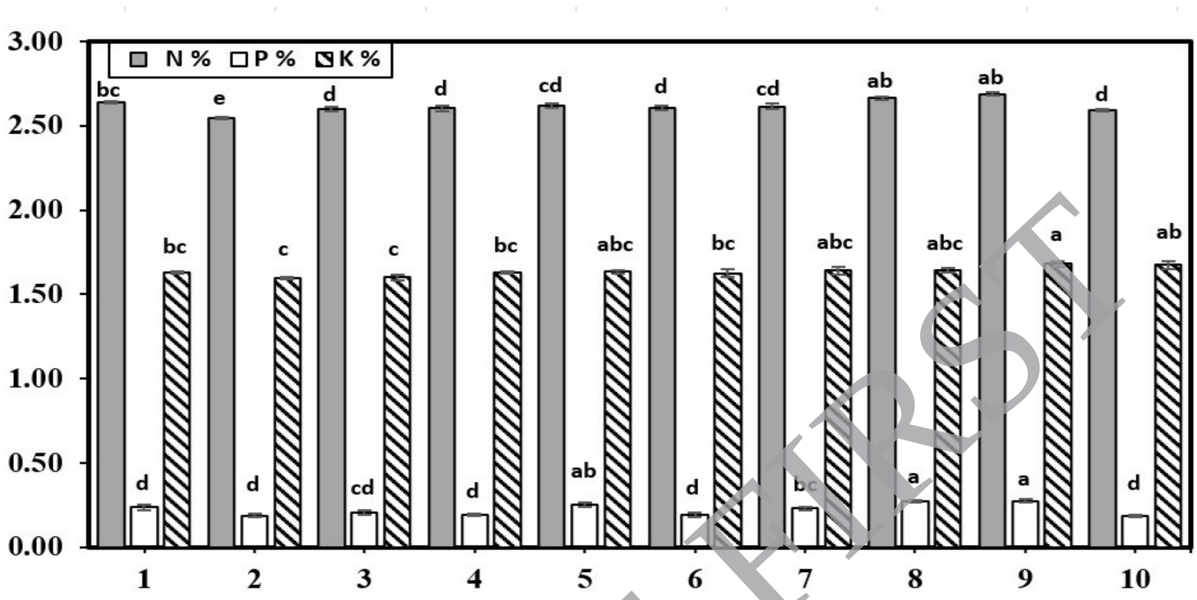

Figure 1: Effect of different treatments on the primary nutrient content (%) of flag leaves at the pretasseling stage of maize. The error bars denote ± 1 SE. Bars with similar lowercase letters are not significantly different with respect to least significant difference (LSD) values at p=0.05

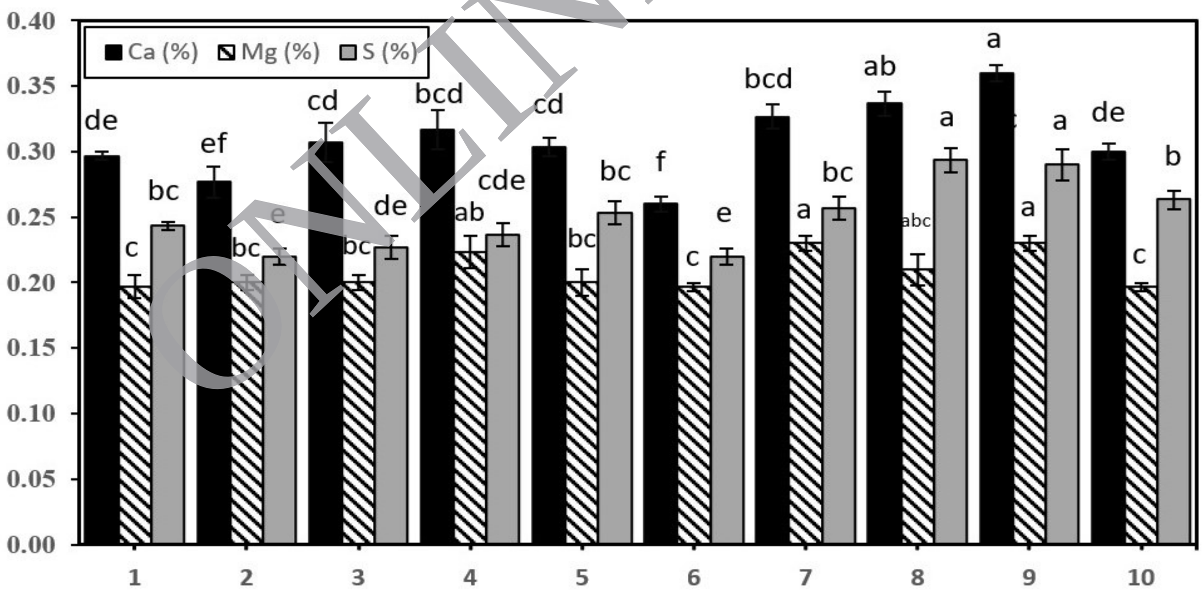

Figure 2: Effect of different treatments on the secondary nutrient content (%) of flag leaves at the pretasseling stage of maize. The error bars denote ± 1 SE. Bars with similar lowercase letters are not significantly different with respect to least significant difference (LSD) values at p=0.05

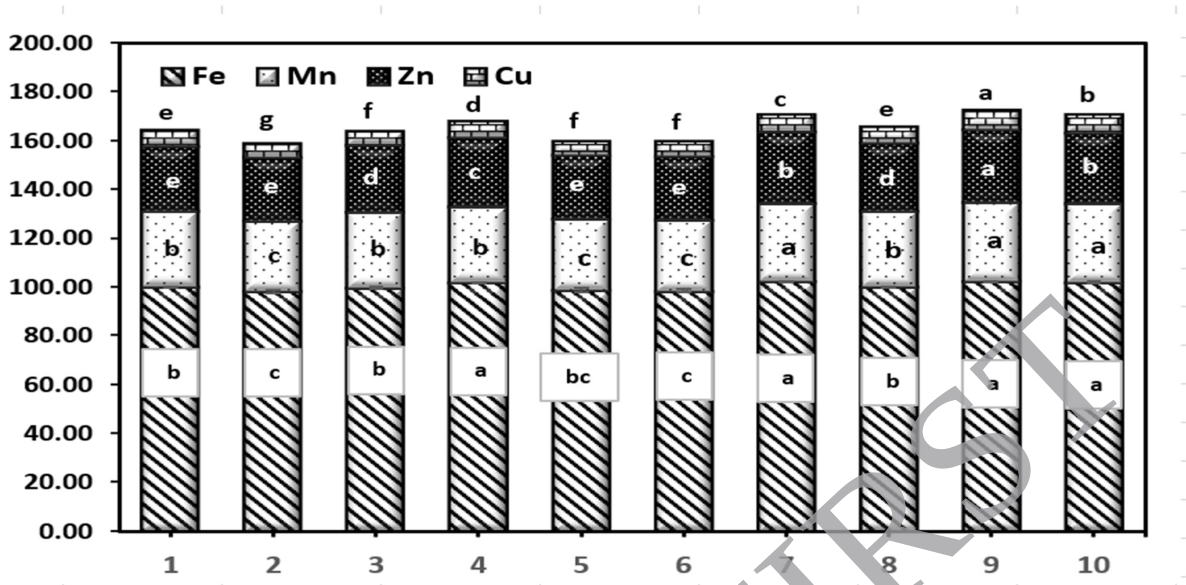

Figure 3: Effect of different treatments on the micronutrient content (ppm) of flag leaves at the pretasseling stage of maize. The error bars denote ± 1 SE. Bars with similar lowercase letters are not significantly different with respect to least significant difference (LSD) values at p=0.05

Total nutrient uptake:

The total macro- and micronutrient uptake by the crop was significantly influenced by the combined application of different sources of nutrients (Figure 4, 5 and 6). Foliar applications of 0.25% Sagarika and 2% water soluble fertilizer (18:18:18) at the knee-high and tasseling stages of maize, along with 75% NPK (T_9), resulted in significantly greater total nutrient uptake by maize than did 100% NPK alone (T_1). However, the application of Sagarika (Soil+ Foliar) or water soluble fertilizers (18:18:18) along with a 75% NPK dose (T_7 and T_5) resulted in total macro- and micronutrient uptake statistically equivalent to 100% NPK alone (T_1). The inclusion of either of the two interventions may reduce the NPK dose by 25%. Moreover, the total nutrient uptake of maize also increased significantly with increasing NPK levels from 75 to 100%. This may be explained by the physiological functions of primary nutrients, viz., N, P and K, in plant nutrition. Mineral elements are required in relatively large quantities throughout the growth period. The majority of cultivated soils are unable to meet the nutrient requirements of field crops because of their native reserves. Therefore, the application of N, P and K in soil tests is of primary concern for sustaining soil productivity in different agro ecosystems. Since nutrient uptake is a function of the nutrient concentration and yield of crops, it is important to identify the best combination of available organic sources with an appropriate proportion of inorganic fertilizers to enhance nutrient concentration, nutrient uptake, and productivity in crops. Salim (2016) reported that the foliar application of seaweed extract increased the micronutrient content in the roots, leaves and grains of wheat plants. Karthik and Jayasri (2023) studied the efficacy of seaweed fertilizers at different concentrations and revealed that the application of seaweed fertilizer derived from *Portieria hornemannii* (seaweed)@30% improved nutrient uptake in mung bean plants compared with that in the control. Due to the steady supply of nutrients throughout the growing period of crops, the combination of organic and inorganic sources resulted in improved nutrient uptake in field crops (Laxminarayana, 2006). In contrast, the treatment of maize seeds with NPK consortia along with 75% NPK (T_6) was less effective at enhancing total nutrient uptake than treatment with 100% NPK (T_1) but was significantly superior to treatment with 75% NPK alone (T_2). NPK consortia (biofertilizers) are low-cost, environmentally friendly, and renewable

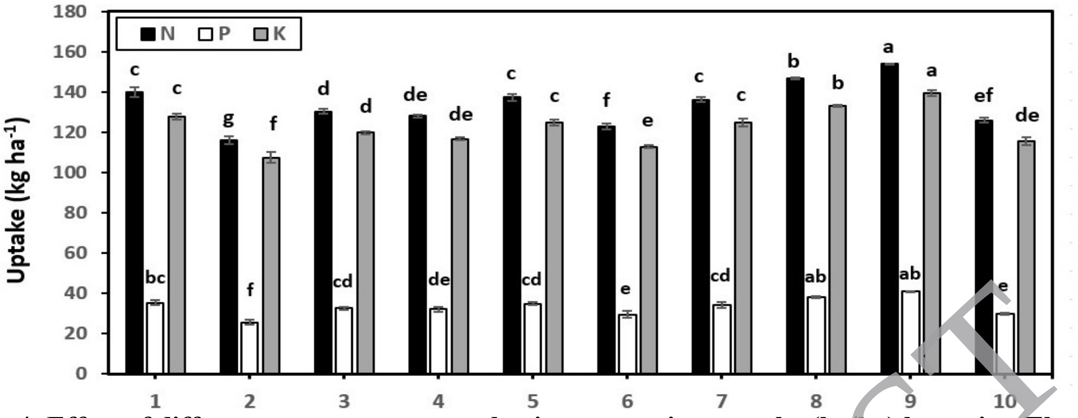

Figure 4: Effect of different treatments on total primary nutrient uptake (kg/ha) by maize. The error bars denote ± 1 SE. Bars with similar lowercase letters are not significantly different with respect to least significant difference (LSD) values at p=0.05

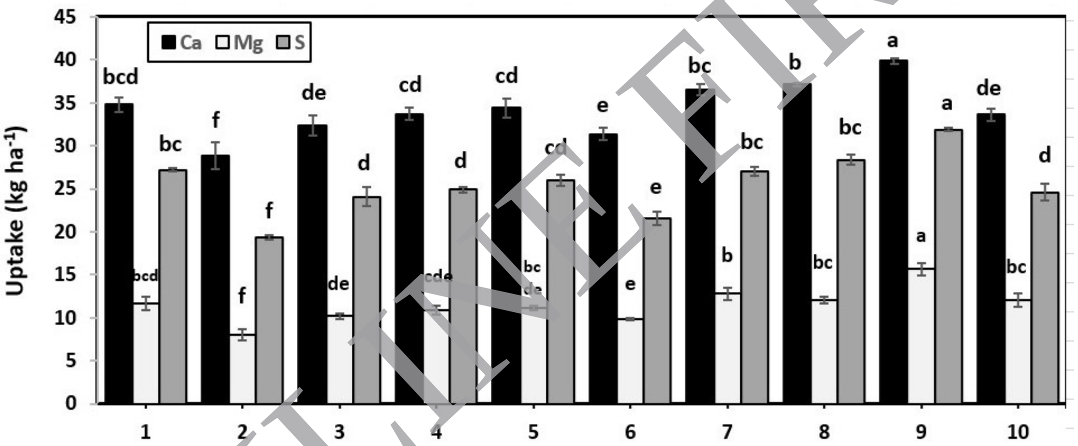

Figure 5: Effect of different treatments on total secondary nutrient uptake (kg/ha) by maize. The error bars denote ± 1 SE. Bars with similar lowercase letters are not significantly different with respect to least significant difference (LSD) values at p=0.05

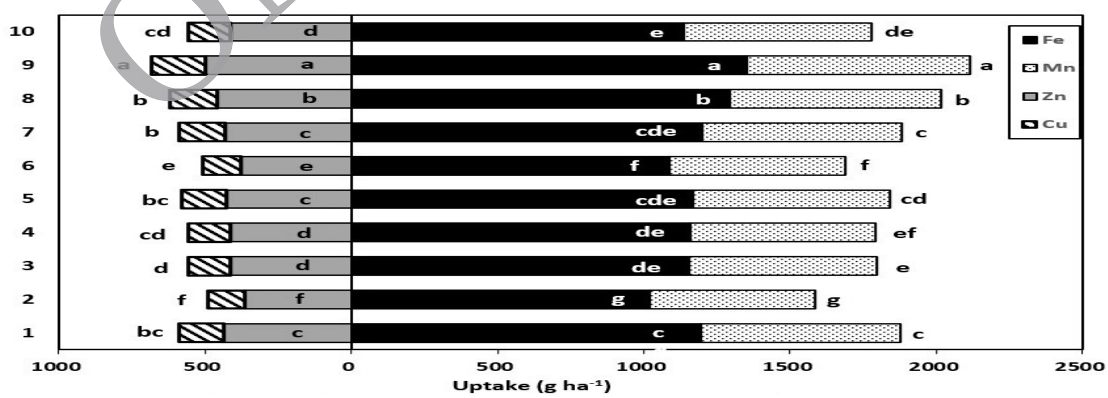

Figure 6: Effect of different treatments on total micronutrient uptake (g/ha) by maize. The error bars denote ± 1 SE. Bars with similar lowercase letters are not significantly different with respect to least significant difference (LSD) values at p=0.05

sources of plant nutrients that can be used to supplement inorganic fertilizers. NPK consortia contain N-fixing (symbiotic & nonsymbiotic) and P & K-solubilizing (through organic acid) bacteria. Although acidic conditions are not suitable for the optimum growth of bacteria, the beneficial effects of NPK consortia on crop productivity and nutrient uptake in moderately acidic soils were comparatively less pronounced. The superiority of T_6 over T_2 for better uptake could be due to the comparatively greater microbial population and mobilization of nutrients, particularly micronutrients, to crops since NPK consortia have the ability to colonize roots or their immediate environment, thus promoting crop growth through physiological and biochemical mechanisms (Delaplace *et al.*, 2015). Similar results were reported by Gohil *et al.* (2021), where the application of RDF + 75% Zn + 75% Fe + a Bio-NPK consortium resulted in the highest N, P and S uptake by rice crops compared with the control.

Conclusion

These findings clearly underscore the positive impact of the effective utilization of diverse nutrient sources in optimizing maize productivity. The study revealed that the combined use of organic and inorganic sources not only amplified the yield but also improved the leaf nutrient status and overall nutrient uptake of the maize crop. Kanchan hybrids of maize responded favorably to the combined application of 75% NPK, the soil and foliar application of Sagarika and the foliar application of water soluble fertilizer (18:18:18).

Conflict of interest

The authors declare that they have no conflicts of interest.

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