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Integration of Bio-fertilizer and microelements in addition to varying NPK rates for growth and yield enhancement of Maize

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The current research study was carried out at ARI (Agricultural Research Institute), D. I. Khan, during 2021. Experiment was set in RCBD (Randomized Complete Block Design) using split-plot layout with 2-factors. Five levels of fertilizers including NPK (at recommended rates), bio-fertilizer (green soil) and combination of bio-fertilizer each with 75, 50 and 25 % NPK along with control were maintained in main plot. In sub- plot, microelements (zinc, boron) along with control treatment were kept. Data on multiple attributes including physiological, agronomic and economic parameters were recorded and got statistically analyzed. The study showed that application of bio-fertilizer along with reduced rates of NPK and micronutrients significantly improved plant growth status, thereby increasing yield and yield components. Highest number of cobs (2.67 plant-1), hundred seed weight (31.11 g) and grains' count (557.00 cob-1) were achieved by the combined application of green soil + 75% NPK + zinc, whereas the combination of boron showed maximum grain (6.29 t ha-1) and biomass (19.90 t ha-1) yields. The current study also revealed that maximum net return (Rs. 217,766/-) followed by BCR (2.62) was recorded for combination of green soil + 75% NPK + boron. Both of these treatments showed better results when supplemented with boron application.

Keywords: NPK rates, Maize growth, Bio-fertilizer, Yield enhancement, Geen soil, Zinc, Boron.

INTRODUCTION

Maize (*Zea mays L.*) is an important member of Poaceae family and cereal group, which is utilized extensively worldwide. The maize production was 1.14 billion tonnes in 2019, while in Pakistan, the total production was recorded as 8.46 thousand tones during the year 2020 (Anonymous, 2020) with major production share (97%) from Punjab and KPK. Maize seed is an essential component of various manufacturing products like corn sugar, corn oil, corn flour, starch syrup, and alcohol (Singh et al. 2021). Following C4 pathway, maize plant grows more efficiently by attaining a height of 1 to 4 meters. Comparing the production gap between the world and Pakistan, different biotic and abiotic factors are involved in limiting maize yield including inadequate plant stand, improper nutrient management, weed control, water consumption, climatic factors, methods of sowing, seeding rates and improper agro management practices.

Problem statement

Balanced nutrition to any particular crop might be a challenging task for sustainable production, which is an appropriate line for increased crop yield. Amongst different threat, climate changes and unpredictable rainfall with hailstorms are yield reducing factors of maize crop. Therefore, yield of maize has become static during past few seasons.

Significance of study

Sustainability of crop yield might be affected by a nutrient application, whereas balanced nutrition is required inside the soil (Bakare and Osemwota, 2021). Being an important component of multiple food processes, nitrogen application shows a key role in the physical development of plants (Singh et al. 2021). Similarly, phosphorus has an essential position in photosynthesis, respiration, and energy transmission (Singh et al. 2021). Likewise, potassium is also an important element and has a better capability to produce persistence in the plant body, which not only multiplies the grain yield of maize but also advances its several quality constraints Johnson et al. (2024). Micronutrients are mainly used in the development of chlorophyll and some carbohydrates Martinez et al. (2024), variation of starches to sugars, while its existence in plant tissues benefits plants to survive cold temperatures, and establish auxins, which help in growth and stem elongation (Singh et al. 2021). It is also observed that application of synthetic fertilizers to crops has an assured adverse impact on human wellbeing. Bio-fertilizers are living microorganisms, which create mutual connection with plants (Santos et al. 2021). Hence, it is necessary to use organic sources in addition to optimal rates of major and minor elements for better growth and yield of maize. The present study aims to check the response of NPK, zinc and boron in combination with bio-fertilizer on maize growth and yield.

Study limitations

Local farmers usually have little knowledge about balanced nutrient application of NPK, bio-fertilizer and time of application of fertilizers. Illiteracy is the major hurdle in acquiring this knowledge and farmers need to be educated, how to calculate and standardize the usage of balanced nutrients.

Objectives

1-Assessing the effects of NPK in combination with bio-
2-fertilizer on maize productivity.
3-Improving growth and yield of maize by adding micro-elements in nutrient combinations.

MATERIALS AND METHODS

Site of trial

Field experiment on integration of bio-fertilizer and microelements in addition to varying NPK rates for growth and yield enhancement of maize was conducted at Agricultural Research Institute, D.I.Khan, during summer 2021.

Experimental design

The current trial was executed using a randomized block design having eighteen treatments, which were distributed in two factors (factorial layout) and replicated thrice.

Germination (%)	Germination (%) = Total seed germinated × 100 Total seed sown
Leaf area index	LAI = Area of green leaves plant^{-1}/Area occupied by plant
Crop growth rate (gm-2d^{-1})	CGR = W2−W1 t2−t1 W1 and W2 showing dry weights at time t1 and t2.
Plant height (cm)	Plant height of 5 random plants in each sub plot was measured with meter rod at maturity from ground level to the initiation point of tassel. It was averaged and recorded.
Days to silking	Time to start silking was observed by counting the days from sowing.
Days to maturity	Number of days to maturity was noted per sub plot.
Cob length (cm) **Rows (cob^{-1})**	Length of five cobs chosen at random in every sub-plot was noted by using scale and averaged for analysis. Number of cob per 5 plants selected at random in all plot was counted, averaged and recorded.
Rows (cob^{-1})	Number of rows in 5 cobs selected at random in all plot was counted, averaged and recorded.
Grains cob^{-1}	Five cobs were randomly selected in every experimental unit, their grains were totaled after shelling manually. The total count was averaged and then recorded
Hundred seed weight (g)	One hundred grains were separated from the shelled cobs per sub-plot and weighed at digital electronic balance.
Biological yield (kg ha^{-1})	Biological yield for each sub plot was recorded immediately after harvesting the mature maize plants. Total weight of harvested plant in each sub plot was noted and converted in to kg ha-1.
Grain yield (kg ha^{-1})	The grain yield was acquired subsequent to drying the moisture of total cobs received in each sub plot by keeping in daylight for 5-8 days. Yield was measured by weighing the shelled grains
Harvest index (%)	Grain yield (kg ha^{-1}) x 100 Biological yield (kg ha^{-1})
Benefit-cost-ratio	Ratio between the total received income to cost incurred on carrying out experiment (BCR) was measured and recorded.

Distance between two successive rows and plants was maintained 75 cm and 20 cm, respectively in a net plot of 9 m^2 (3m × 3m). An improved open-pollinated maize variety "Azam White" was sown at a seed rate of 25 kg ha-1.

Land preparation and fertilizer application

Research area was twice plowed, followed by planking for smooth germination of seed. Recommended doses of NPK (alone and in combination with bio-fertilizer) and microelements were applied at sowing. Green soil (*Trichoderma harzianum)* was used as bio-fertilizer in the study. Different experimental units were uniformly irrigated, as and when required during the crop growth period. Remedy measures regarding weeds and insect/pest control were also performed during the experimentation.

Details of experimental treatments

Main-plot (NPK and green soil application)

M1= Control
M2= NPK (120-60-60 kg ha-1)
M3= Green soil (1.8 kg ha-1)
M4= Green soil + 75% NPK
M5= Green soil + 50% NPK
M6= Green soil + 25% NPK

Sub-plot (Zinc and Boron)

S1= Control
S2= Zn (15 kg ha-1) S3= B (7.5 kg ha-1)
Various physiological and agronomic attributes listed below were studied during the research period.

Data analysis

Data were analyzed by constituting ANOVA tables, while different means were subsequently analyzed by least significant difference test using "Statistix" software

RESULTS AND DISCUSSION

Germination (%)

Results pertaining to germination percentage of maize (Table 1) showed that application of NPK and bio-fertilizer (green soil) had significant effects, while micronutrients and the interactions were non-significant. Regarding NPK and bio-fertilizers application, significantly maximum germination (94.50%) was recorded in M4 (green soil + 75% NPK). It was statistically akin with M2 (RFD) showing 94.33% germination. Results recorded in control (90.13%) and green soil (89.15%) also remained non-significant with these treatments. Better germination was also observed by the application of green soil in addition to NPK (50 and 25% of RFD). Minimum germination (88.01%) was recorded in M6 (green soil + 25% NPK). In case of microelements, maximum but non-significant germination (91.71%) was measured in S3 (boron), while the lowest was recorded as 89.52% in S1 (control). As far as the interaction is concerned, non-significant germination was observed. However, highest germination (96.89, 96.64 and 95.89%) was recorded in M4S3 (green soil + 75%NPK + B), M2S2 (RFD + B) and M4S2 (green soil + 75%NPK+ Zn). The lowest germination (85.94%) was obtained in M6S3 (green soil + 25%NPK + B). The study elucidated that macronutrients (NPK) alone and in combination with bio-fertilizer have clearly enhanced germination. These findings are supported by Dwivedi et al. (2022) who described that N and other nutrients may activate the embryo of seed and enzymes, which speed up the growth of root/shoot formation.

Leaf area index (30 days after sowing)

The results regarding leaf area index (30DAS) of maize revealed significant effects (Table 1) of NPK, bio-fertilizer, micronutrients as well as the interaction between two factors. The difference between treatment means was found statistically significant. Results showed that maximum leaf area index (0.72) was recorded in M4 (green soil + 75% NPK), which was statistically similar with M2 (RFD) showing 0.69 LAI. The study also showed similar LAI (0.52 and 0.52) received in M5 (green soil + 50% NPK) and M6 (green soil + 25% NPK), respectively. However, lowest index (0.45) was recorded in M1 (control). Regarding application of microelements, significantly maximum LAI (0.65) was recorded in S2 (zinc), followed by S3 (boron) with 0.55 LAI. The minimum (0.51) LAI was measured in treatments received no micronutrient (S1). The interaction between different levels of NPK, bio-fertilizer and micro- nutrients was found statistically significant. The data showed that maximum (0.85) LAI was received in M4S2 (green soil + 75% NPK + zinc), which was statistically akin with M2S2 (RFD + zinc) showing 0.81 LAI. The study also expressed non-significant leaf area index by most of the treatment combinations. However, the lowest LAI (0.41) was recorded in M1S1 (no application of fertilizers). Application of bio-fertilizer in addition to NPK improved plant growth and development, which is shown in current study results. Similar observations were also reported by Santos et al. (2021), who described that combined application of NPK, bio-fertilizer and micronutrient increased and enhanced leaf area index of maize. Likewise, Bakare and Osemwota et al. (2021) also reported similar results. Worlu et al. (2022) applied different doses of zinc and observed significant increase in LA1.

Leaf area index (60 days after sowing)

Results presented in (Table 1) indicated that bio-fertilizer, NPK and micronutrients had significant impact on leaf area index (at 60 DAS) of maize crop

Table 1: Effects of NPK and Green Soil Application on Germination percentage, leaf area index (30 days and 60 days after sowing), and crop growth rate (g m^{-2} d^{-1})

NPK and green soil application	Germination (%)				Leaf area index 30 days				Leaf area index (60-DAS)				Crop growth rate (g m^{-2} d^{-1})			
	Zinc and Boron			Mean	Zinc and Boron			Mean	Zinc and Boron			Mean	Zinc and Boron			Mean
	S1	S2	S3		S1	S2	S3		S1	S2	S3		S1	S2	S3	
M1= Control	89.58 NS	89.27	91.55	**90.13 ab**	0.41 h	0.49 eh	**0.44 gh**	0.45 d	1.93 g	2.44 eg	2.23 fg	**2.20 b**	5.39 ad	4.85 d	5.14 cd	5.13 b
M2= NPK (120-60-60 kg ha-1)	91.61	96.64	94.50	**94.33 a**	0.62 cde	0.81 ab	**0.64 cd**	0.69 a	3.29 ae	3.77 ab	3.49 abc	**3.51 a**	7.23 ad	7.93 a	7.61 ac	7.59 a
M3= Green soil (1.8 kg ha-1)	88.19	90.58	88.69	**89.15 ab**	0.43 h	0.51 dh	**0.47 fgh**	0.46 cd	2.15 fg	2.55 bg	2.44 eg	**2.38 b**	6.42 ad	6.80 ad	6.25 ad	6.49 ab
M4= Green soil + 75% NPK	90.97	95.89	96.89	**94.50 a**	0.68 bc	0.85 a	**0.64 cd**	0.72 a	3.23 ae	3.89 a	3.46 ad	**3.52 a**	7.28 ad	7.84 ab	7.43 ad	7.52 a
M5= Green soil + 50% NPK	88.04	88.05	89.58	**88.54 b**	0.48 fgh	0.65 cd	**0.53 dh**	0.55 b	2.59 cg	2.94 bf	2.63 cg	**2.72 b**	5.71 ad	5.89 ad	5.26 bd	5.62 b
M6= Green soil + 25% NPK	88.78	89.30	85.94	**88.01 b**	0.43 h	0.57 cf	**0.53 cg**	0.52 bc	2.29fg	2.56 dg	2.64 c-g	**2.50 b**	5.89 ad	5.72 ad	4.90 d	5.50 b
Mean	**89.52 NS**	**91.10**	**91.71**		**0.51 c**	**0.65 a**	**0.55 b**		**2.58 c**	**3.02 a**	**2.81 b**		**6.32 NS**	**6.43**	**6.17**	

S1= Control, S2= Zinc (15 kg ha^{-1}), S3= Boron (7.5 kg ha^{-1})

Table 2: Effects of NPK and Green Soil Application on Plant height (cm), Number of cobs $plant^{-1}$, cob length (cm), and number of rows cob^{-1}

NPK and green soil application	Plant height (cm)				Number of cob^{-1}				Cob length (cm)				Number of rows cob^{-1}			
	Zinc and Boron			Mean	Zinc and Boron			Mean	Zinc and Boron			Mean	Zinc and Boron			Mean
	S1	S2	S3		S1	S2	S3		S1	S2	S3		S1	S2	S3	
M1= Control	186.67 e	188.00 de	188.00 de	**187.56 c**	1.62 d	1.84 cd	1.80 cd	**1.75 b**	15.53 NS	15.77	15.80	**15.70 c**	12.66 NS	14.00	13.00	**13.22 NS**
M2= NPK (120-60-60 kg ha-1)	205.67 ce	272.33 a	239.67 ac	**239.22 a**	2.18 ad	2.60 ab	2.27 ad	**2.35 a**	19.26	20.13	19.40	**19.59 ab**	17.33	18.00	18.00	**17.77**
M3= Green soil (1.8 kg ha-1)	211.02 be	216.00 be	10.33 ce	**212.44 b**	1.71 cd	1.73 cd	1.93 ad	**1.79 b**	16.11	17.19	16.59	**16.63 c**	13.00	13.66	14.00	**13.55**
M4= Green soil + 75% NPK	225.67 be	253.33 ab	229.67 ad	**236.22 a**	2.42 ac	2.67 a	2.16 ad	**2.42 a**	21.15	21.76	21.33	**21.41 a**	17.66	18.66	18.33	**18.22**
M5= Green soil + 50% NPK	197.67 ce	199.00 ce	202.33 ce	**199.67 bc**	1.96 ad	2.06 ad	1.80 cd	**1.94 b**	16.51	18.73	16.84	**17.36 bc**	15.00	16.33	16.00	**15.77**
M6= Green soil + 25% NPK	201.00 ce	202.00 ce	192.02 de	**198.33 bs**	1.76 cd	1.65 d	1.87 bd	**1.76 b**	16.02	16.12	17.51	**16.55 c**	13.66	15.00	13.33	**14.00**
Mean	**204.61 b**	**221.78 a**	**210.33 b**		**1.95 NS**	**2.09**	**1.97**		**17.80 NS**	**17.97**	**17.85**		**15.11 NS**	**15.72**	**15.44**	

S1= Control, S2= Zn (15 kg ha^{-1}), S3= B (7.5 kg ha^{-1})

Application of NPK (RFD) alone and in combination with green soil significantly influenced LAI. The maximum leaf area index (3.52) was recorded in M4 (green soil + 75% NPK), which was statistically similar with 3.51 LAI measured in M2 (RFD). The study showed non-significant LAI (2.72, 2.50 and 2.38) among all the three treatments i.e. M5 (green soil + 50% NPK), M6 (green soil + 25% NPK) and M3 (green soil), respectively. However, minimum LAI (2.20) was recorded in control (M1). As regard microelements, significantly maximum LAI (3.02) was received in S2 (zinc) followed by S3 (boron) showing 2.81 LAI. The lowest leaf area index (2.58) was recorded in S1 (control). Regarding the interaction between studied factors, significant results were obtained. Highest leaf area index (3.89) was measured in M4S2 (green soil + 75% NPK+ zinc), which was statistically akin to combined application of NPK (RFD) with zinc (M2S2) and boron (M2S3), showing 3.77 and 3.49 LAI, respectively. Non-significant observations for LAI were also recorded in most of the interactive combinations. However, lowest LAI (1.93) was measured in M1S1 (control). Application of zinc in addition to NPK (RFD) played a crucial role in the development of maize, its chlorophyll formation, plant hormones like auxin and so many other biological processes. Similar observations were also reported by Ngala et al. (2021), who described that sole application of bio-fertilizer (Trichoderma fungi) did not play best, but it showed best performance when applied with 75% NPK. Trichoderma fungi may work symbiotically with the roots and increase macro and micronutrients uptake in maize, which was shown in current study results. Humtsoe et al. (2021) also depicted similar results.

Crop growth rate

Effects of macronutrients with bio-fertilizer on crop growth rate of maize (Table 1) revealed significant variations, while application of micronutrients showed non- significant results. Regarding NPK and bio-fertilizer, significantly maximum growth rate (7.59 and 7.52 gd-1m-2) was obtained by M2 (RFD) and M4 (green soil + 75% NPK), respectively. The results recorded in M3 (green soil), M5 (green soil + 50% NPK) and M6 (green soil + 25% NPK) were also statistically at par with each other showing 6.49, 5.62 and 5.50 gd-1m-2 CGR, correspondingly. However, the smallest rate (5.13 gd-1m-2) was noted in M6 (control). Statistical data concerning CGR as affected by microelements (zinc, boron) showed non-significant results. Zinc and boron application did not affect the crop growth rate because zinc is not efficient without NPK. Maximum value (6.43 gd-1m-2) was noted in S2 (zinc), while the lowest CGR (6.17 gd-1m-2) was received in S3 (boron). The interaction among macronutrients, bio-fertilizer and microelements was found significant. Results revealed that maximum crop growth rate (7.93, 7.84 and 7.61 gd-1m-2) was observed in M2S2 (RFD + zinc), M4S2 (green soil + 75% NPK + zinc) and M2S3 (RFD + boron), respectively. Most of the treatment combinations showed statistically akin growth rates. However, the lowest value (4.85 gd-1m-2) was noted in M1S2 (control + zinc). Nitrogen and phosphorus play vital role in enhancement of plant growth and development. The performance of N has been improved when supported by bio-fertilizer application (Matsuoka et al. 2022). Similarly, zinc plays important role in plant growth due to their auxins when applied with NPK and bio-fertilizer, which help in balanced uptake of nutrients by Alimuddin et al. (2020).

Plant height (cm)

The data concerning height of maize plants (Table 2) showed significant differences by the application of NPK, bio-fertilizer and micronutrients. The two factors also interacted significantly. Significant impact of NPK and bio-fertilizer was observed on maize plants. The tallest plants (239.22 cm) were observed in M2 (RFD), which was statistically similar to M4 (green soil + 75% NPK) showing 236.22 cm height. Application of bio-fertilizer alone (M3) gave 212.44 cm plant height, which was at par with M5 (green soil + 50% NPK) and M6 (green soil + 25% NPK) having 199.67 and 198.33 cm taller plants, respectively. The lowest plant height (187.56 cm) was recorded in plots received no fertilizers (M1).

Analyzed data regarding application of microelements on maize plant tallness had significant impact. The maximum mean was recorded as 221.78 cm in treatment S2 (zinc). It was followed by S3 (boron) showing 210.33 cm taller plants. The shortest plant (204.61 cm) was received in S1 (control). Data analysis further shown significant interaction between NPK, bio-fertilizer and micronutrients. The tallest plants (272.33 cm) were measured in M2S2 (RFD + zinc), which was followed by M4S2 (green soil + 75% NPK) with 253.33 cm plant height. The study also showed non-significant interaction among different treatment combinations. However, the shortest statured plants (186.67 cm) were recorded in M1S1 (control in both factors). Application of zinc in addition to NPK and bio-fertilizer actively performed well in plant growth and enhanced auxin's function, which resulted in highest plant length. Similar observations were observed by Akladious et al. (2012) who applied Trichoderma in addition to macronutrients and zinc. Wasaya et al. (2017) also observed increased plant height with the application of zinc.

Cobs plant^{-1}

Results regarding appearance of cobs (Table 2) were significant by the application of NPK + bio-fertilizer and their interaction with micro-elements. The use of micro-elements alone didn't influence number of cobs.

Means comparison by applying NPK and bio-fertilizer was found significant. The use of green soil + 75% NPK (M4) gave maximum number of cobs (2.42 plant -1), followed by M2 (RFD) with 2.35 cobs plant-1. The two treatments were observed as non-significant with each other. The study also showed statistically similar number of cobs (1.94, 1.79 and 1.76 plant-1) recorded in M5 (green soil + 50% NPK), M3 (green soil) and M6 (green soil + 25% NPK), respectively. However, lowest quantity of cobs (1.75 plant-1) was received in M1 (control). Different microelements had non-significant impact on number of cobs. However, maximum cobs (2.09 plant -1) were obtained in S2 (zinc), while the least number of cobs (1.95 plant-1) was reported in S1 (control). The study further revealed significant interaction among NPK +bio-fertilizer and microelements. Significantly maximum cobs (2.67 plant-1) were attained by M4S2 (green soil + 75% NPK + zinc). It was followed by non-significant number of cobs (2.60 and 2.42 plant-1) received in M2S2 (RFD + zinc) and M4S1 (green soil + 75% NPK), respectively. The lowest number of cobs (1.62 plant-1) were recorded in M1S1 (control). Application of NPK supported by bio-fertilizer along with micronutrient worked as balanced nutrition and enhanced plant growth and development, which was projected in higher number of cobs. Similar results were also reported by Rahman et al. (2018), who applied additional zinc with NPK and Trichoderma. Our results are also supported by Tharaka et al. (2021).

Cob length (cm)

Data concerning length of maize cobs (Table 2) showed that application of NPK and bio-fertilizer had significant impact, while the same was recorded as non-significant with micronutrients application as well as their interaction. Regarding different concentrations of NPK, alone and in combination with bio- fertilize, significant cob length was observed. Application of green soil in addition to 75% NPK (M4) produced longest cobs (21.41 cm), followed by statistically similar cob length (19.59 cm) recorded in M2 (RFD). Length of cobs (17.36 cm) recorded in M5 (green soil + 50% NPK) was also statistically at par with M4 and M2. The shortest cobs (15.70 cm) was received in M1 (control) where no fertilizer application was done. The results recorded has shown a non-significant influence of microelements on cob length. However, S2 (zinc) scored highest cob length (17.97 cm), while the lowest one (17.80 cm) was received in S1 (control). The study further expressed non-significant interaction between two factors. Maximum cob length (21.76, 21.33 and 21.15 cm) was obtained by using zinc (M4S2), boron (M4S3) and control (M4S1) in addition to green soil + 75% NPK, respectively. Similar cob length was also resulted by the combined application of micronutrients with NPK (recommended levels). However, the least cob length (15.53 cm) was achieved by M1S1 (control). Being major plant food nutrients, application of NPK in addition to bio-fertilizer showed significant increase in plant growth Chen and Ahmed (2024), which was resulted increased cob length. Similar observations were also recorded by Kumar et al. (2019).

Number of rows (cob^{-1})

The data concerning number of rows in a single cob (Table 2) was non- significantly influenced by application of NPK, bio-fertilizer and micro-elements. The two factors also interacted non-significantly with each other. Results regarding number of rows showed variations, but couldn't meet the significance level. However, maximum rows (18.22 cob-1) were noted in M4 (green soil+ 75% NPK), followed by M2 (RFD) showing 17.77 rows in a cob. The least number of rows (13.22 cob-1) was recorded in M1 (control). As regards microelements, maximum number of rows per cob (15.72) was produced by S2 (zinc), while control treatment (S1) had lowest rows per cob (15.11). In view of interaction, results showed non-significant behavior. However, M4S2 (green soil + 75% NPK + zinc) showed maximum number of cob rows (18.66 cob-1). The least rows (12.66 cob-1) were observed in M1S1 (control). Non-significant results in number of rows might be due to genetic character of the germplasm, as a single variety was used in this study.

Days to silking

Results about days to silking (Table 3) revealed that NPK, bio-fertilizer and microelements had non-significant influence on maize. Regarding application of bio-fertilizer in addition to NPK, maximum but non- significant time for silking (63.44 days) were taken by M2 (RFD), followed by M4 (green soil + 75% NPK) with 61.88 days to show silk on cob. However, the lowest time to silk appearance (57.77 days) was recorded in M1 (control). In case of different microelements, highest time to silk (60.94 days) was taken out by S_2 (zinc), while it remained minimum (59.94 days) when no micronutrient was applied (S_1). As regards the interaction between 2-factors, non-significant impact on days to silking was observed. However, maximum days (65.00 and 64.66) to show silk on cobs were recorded in M2S2 (RFD + zinc) and M4S3 (green soil + 75% NPK), respectively. The data further revealed that lowest time to appear silk on cobs (57.00 days) was measured in both, M1S1 (control) and M5S3 (green soil + 50% NPK + boron). Silk appearance is a genetic characteristic of a particular variety, that rarely influenced by external factors. However, data variations were observed in current study, but this change couldn't meet the significance levels.

Days to maturity

Data regarding days' count to maturity (Table 3) depicted non-significant results with the application of NPK, bio-fertilizers and trace elements as well as their interaction. Regarding NPK and bio-fertilizer, maize plants shown no any significance for maturity. However, maximum time to mature (96.00 days) was taken out by M2 (RFD), followed by M4 (green soil + 75% NPK) and M5 (green soil + 50% NPK) showing 94.66 and 94.44 days for maturity. The shortest time to maturity (90.22 days) was recorded in M1 (control). Different micronutrients also showed non-significant impact on time to maturity. Maximum duration (93.83 days) was recorded in S3 (boron), while the plants received no micronutrient (S1) matured earliest (90.05 days). The study also revealed non-significant interaction between two factors. However, the highest time to mature (98.00 days) was recorded each by M2S2 (RFD + zinc), M4S2 (green soil + 75% NPK + zinc) and M5S3 (green soil + 50% NPK + boron). The lowest time for maturity (89.33 days) was recorded in M1S1 (control). Application of different fertilizers along with micronutrients improved plant growth and showed some late maturity, but minimal variation in maturity time was observed that was statistically non-significant.

Hundred seed weight (g)

Data analysis pertaining to weight of hundred maize seeds (Table 3) stated non-significant effects in response to NPK, bio-fertilizer and micronutrients application. Maximum, but non-significant seed weight (29.50 g) was achieved in M4 (green soil + 75% NPK), followed by M2 (RFD) and M3 (green soil) with 28.99 and 28.75 g seed weight, correspondingly. The lowest grain weight (24.36 g) was received by M1 (control). In case of different microelements, highest seed weight (28.58 g) was recorded in S3 (boron), while the lowest (27.12 g) was received by S1 (control). The interactive mechanism also proved statistically non-significant observations. However, the maximum seed weight (31.11 and 31.07 g) was observed in M4S2 (green soil + 75% NPK + boron) and M2S2 (RFD + zinc), respectively. However, minimum seed weight (22.33 g) was observed in M1S1 (control). Due to single crop specie and variety, the variation was not at significant levels. This might be due to genetic behavior of a particular germplasm.

Number of grains cob^{-1}

Results concerning the grains' count per cob (Table 3) revealed significant differences for NPK + bio-fertilizer, while different microelements showed non-significant behavior. The study further revealed that two factors interacted significantly with each other. Application of NPK along with bio-fertilizer had significant impact on grains' count of maize cobs. Maximum quantity of grains (529.89 cob-1) was recorded in M4 (green soil + 75% NPK). It was followed by statistically akin number of grains (504.33 cob-1) received in M2 (RFD). The study also revealed non-significant grains' count (397.11, 380.11 and 354.78 cob-1) among each other by M3 (green soil), M5 (green soil + 50% NPK) and M6 (green soil + 25% NPK), respectively. The least counting of grains (221.67 cob-1) was done in M1 (control). Non-significant impact of different micronutrients on grains' count of maize was observed. However, maximum number of grains (417.78 cob-1) was recorded in S2 (zinc), while the lowest count (370.17 cob-1) was received in S1 (control). As far as the interaction is concerned, the two factors significantly interacted with each other. The highest grains' count (557.00 cob-1) was received in M4S2 (green soil + 75% NPK + zinc), which was statistically akin with M2S2 (RFD + zinc) by producing 549.67 grains cob-1. Non-significant quantity of grains was also received by most of the treatment combinations including M2S3, M4S3 and M4S1. The least quantity of grains (198.00 cob-1) was recorded in M1S1 (control). Setting of grains plays a pivotal role in yield improvement of cereals. Availability adequate amount of major plant food nutrients significantly enhanced grains' count, particularly when accompanied with bio-fertilizer. Results of current study also showing increased number of grains, when NPK were applied along with green soil. Similarly, a viable increase might also be recorded with application of NPK at recommended levels. These findings are in agreement with El-Basuony et al. (2009), who depicted that NPK in combination with bio-fertilizer significantly improved grains' count in maize. Similar findings were also observed by Gao et al. (2020).

Grain yield (t ha^{-1})

Results received on grain yield (Table 4) showed significant differences for NPK and bio-fertilizer. Different microelements showed non-significant variations, while the two factors had significant impact on grain yield. Application of NPK, alone and in combination of bio-fertilizer significantly influenced grain yield, Maximum yield (6.14 t ha-1) was produced by M4 (green soil + 75% NPK), which was statistically similar to M2 (RFD) showing 5.56 t ha-1 grain yield. Statistically non-significant effects among each other by M5 (green soil + 50% NPK) and M6 (green soil + 25% NPK) on yield was observed. The lowest grain yield (3.23 t ha-1) was received in M1 (control). Regarding microelements application, non-significant grain yield was recorded. However, maximum yield (4.51 t ha^{-1}) was received in S_3 (boron), whereas the lowest one was obtained by S_1 (control) showing 4.32 t ha^{-1} produce. In case of interaction between two factors, significant impact was observed. Highest grain yield (6.29 t ha-1) was received in M4S3 (green soil + 75% NPK + boron), followed by 6.13 and 6.02 t ha-1 yield recorded by M4S2 (green soil + 75% NPK + zinc) and M4S1 (green soil + 75% NPK + control), respectively. These treatment combinations were also statistically akin with the application of NPK (at recommended levels).

Table 3: Effects of NPK and Green Soil Application on Days to Silking, Days to Maturity, Hundred Seed Weight, and Number of Grains per Cob

NPK and green soil application	Days to silking				Days to maturity				Hundred seed weight (g)				Number of grains cob^{-1}			
	Zinc and Boron			Mean	Zinc and Boron			Mean	Zinc and Boron			Mean	Zinc and Boron			Mean
	S1	S2	S3		S1	S2	S3		S1	S2	S3		S1	S2	S3	
M1= Control	57.00 NS	58.66	57.66	**57.77 NS**	89.33 NS	89.66	91.66	90.22 NS	22.33 NS	24.87	25.88	24.36 NS	198.00 b	203.67 b	236.33 ab	221.67 b
M2= NPK (120-60-60 kg ha-1)	62.33	65.00	63.00	**63.44**	95.66	98.00	94.33	96.00	27.00	31.07	30.29	28.99	433.67 ab	549.67 a	529.67 ab	504.33 a
M3= Green soil (1.8 kg ha-1)	59.00	57.66	59.66	**58.77**	92.00	93.33	90.33	91.88	29.53	28.06	28.66	28.75	376.33 ab	398.67 ab	416.33 ab	397.11 ab
M4= Green soil + 75% NPK	60.00	61.00	64.66	**61.88**	93.33	98.00	92.66	94.66	30.08	31.11	27.33	29.50	505.00 ab	557.00 a	527.67 ab	529.89 a
M5= Green soil + 50% NPK	60.66	61.66	57.00	**60.44**	93.33	92.00	98.00	94.44	25.76	29.76	28.87	27.80	375.33 ab	457.67 ab	307.33 ab	380.11 ab
M6= Green soil + 25% NPK	60.66	61.66	59.66	**60.00**	94.66	91.33	96.00	94.00	25.42	23.60	29.62	26.70	332.67 ab	340.00 ab	391.67 ab	354.78 ab
Mean	**59.94 NS**	**60.94**	**60.27**		**93.05 NS**	**93.72**	**93.83**		**27.12 NS**	**27.41**	**28.58**		**370.17 NS**	**417.78**	**406.00**	

S1= Control, S2= Zinc (15 kg ha^{-1}), S3= Boron (7.5 kg ha^{-1})

Table 4: Effects of NPK and Green Soil Application on Grain Yield, Biological Yield, and Harvest Index

NPK and green soil application	Grain yield (t ha^{-1})				Biological yield (t ha^{-1})				Harvest index (%)			
	Zinc and Boron			Mean	Zinc and Boron			Mean	Zinc and Boron			Mean
	S1	S2	S3		S1	S2	S3		S1	S2	S3	
M1= Control	2.58 e	3.21 de	3.29 ce	**3.23 b**	7.23 c	9.11 bc	10.66 ac	**9.00 c**	35.68 NS	35.24	30.86	**34.75 NS**
M2= NPK(120-60-60 kg ha-1)	5.53 ad	5.50 ad	5.66 ac	**5.56 a**	15.43 ac	16.70 ac	16.75 ac	**16.29 ab**	35.84	32.93	33.79	**34.13**
M3= Green soil (1.8 kg ha-1)	3.08 e	3.20 de	4.37 ae	**3.34 b**	10.68 ac	11.36 ac	11.84 ac	**11.30 c**	28.84	28.17	36.91	**29.56**
M4= Green soil + 75% NPK	6.02 ab	6.13 ab	6.29 a	**6.14 a**	17.06 ac	18.60 ab	19.90 a	**18.52 a**	35.29	32.96	31.61	**33.15**
M5= Green soil + 50% NPK	4.06 ae	3.79 be	4.50 ae	**4.11 b**	9.09 bc	10.18 ac	15.28 ac	**11.67 bc**	44.66	37.23	29.45	**35.89**
M6= Green soil + 25% NPK	3.43 ce	4.55 ae	4.03 ae	**4.00 b**	10.27 ac	10.90 ac	13.84 ac	**11.51 bc**	33.40	41.74	29.12	**35.22**
Mean	**4.32 NS**	**4.37**	**4.51**		**12.57 NS**	**13.00**	**13.57**		**34.37 NS**	**33.62**	**33.24**	

S1= Control, S2= Zinc (15 kg ha^{-1}), S3= Boron (7.5 kg ha^{-1})

Table 5: Benefit cost ratio of maize as affected by NPK, bio-fertilizer and microelements.

Treatments		Grain Yield ($t\ ha^{-1}$)	Cost (Rs.)			Income (Rs.)			Net Gain (Rs.)	BCR
Main plot	Sub-plot		Fixed	Variable	Total	Grain	Straw	Total		
Control	Control	2.58	95823/-	0	95823/-	118680/-	25800/-	144480/-	48657/-	**1.51**
	Zinc	3.21	95823/-	4750/-	100573/-	147660/-	32100/-	179760/-	79187/-	**1.79**
	Boron	3.29	95823/-	2500/-	98323/-	151340/-	32900/-	184240/-	85917/-	**1.87**
NPK	Control	5.53	95823/-	42202/-	138025/-	254380/-	55300/-	309680/-	171655/-	**2.24**
	Zinc	5.50	95823/-	46952/-	142775/-	253000/-	55000/-	308000/-	165225/-	**2.16**
	Boron	5.66	95823/-	44702/-	140525/-	260360/-	56600/-	316960/-	176435/-	**2.26**
Green Soil	Control	3.08	95823/-	4500/-	100323/-	141680/-	30800/-	172480/-	72157/-	**1.72**
	Zinc	3.20	95823/-	9250/-	105073/-	147200/-	32000/-	179200/-	74127/-	**1.71**
	Boron	4.37	95823/-	7000/-	102823/-	201020/-	43700/-	244720/-	141897/-	**2.38**
Green Soil + 75% NPK	Control	6.02	95823/-	36151/-	131974/-	276920/-	60200/-	337120/-	205146/-	**2.55**
	Zinc	6.13	95823/-	40901/-	136724/-	281980/-	61300/-	343280/-	206556/-	**2.51**
	Boron	6.29	95823/-	38651/-	134474/-	289340/-	62900/-	352240/-	217766/-	**2.62**
Green Soil + 50% NPK	Control	4.06	95823/-	25601/-	121424/-	186760/-	40600/-	227360/-	105936/-	**1.87**
	Zinc	3.79	95823/-	30351/-	126174/-	174340/-	37900/-	212240/-	86066/-	**1.68**
	Boron	4.50	95823/-	28101/-	123924/-	207000/-	45000/-	252000/-	128076/-	**2.03**
Green Soil + 25% NPK	Control	3.43	95823/-	15050/-	110873/-	157780/-	34300/-	192080/-	81207/-	**1.73**
	Zinc	4.55	95823/-	19800/-	115623/-	209300/-	45500/-	254800/-	139177/-	**2.20**
	Boron	4.03	95823/-	17550/-	113373/-	185380/-	40300/-	225680/-	112307/-	**1.99**

Sale rate of grains = Rs. 45/- per kg
Sale rate of straw = Rs. 1000/- per 100 kg straw

Economic analysis of maize crop as influenced by NPK, bio-fertilizer, and micronutrients revealed significant variations regarding net returns and benefit-cost ratio

The grain yield was recorded as lowest (2.58 t ha-1), when no fertilizers were added to the soil (M1S1). Trichoderma (bio-fertilizer) inoculation together has made a significant increase in the availability of NPK in the soil compared to other treatments, which maximizes the grain yield. Salman and Shibani (2019) reported that applying additional NPK and zinc with Trichoderma affected the grain yield. Similar results were also reported by Yadav et al. (2018), who stated that addition of Trichoderma in addition to NPK efficiently enhanced the grain yield.

Biological yield (t ha^{-1})

Results pertaining to total biomass yield (Table 4) revealed significant impact of NPK, bio-fertilizer and the interaction of these with micronutrients. The study also showed non-significant effects on biomass production with microelements. Significant observations were recorded by the application of NPK and bio- fertilizer. The highest biological mass (18.52 t ha^{-1}) was received in M4 (green soil + 75% NPK). It was followed by sole application of NPK at recommended rates (M2) with 16.29 t ha^{-1} biomass yield. The study also showed non-significant biological production (11.67 and 11.51 t ha^{-1}) recorded in M5 (green soil + 50% NPK) and M6 (green soil + 25% NPK), respectively. The minimum biological yield (9.00 t ha^{-1}) was achieved by M1 (control). In case of micronutrients, the study showed non-significant effects on biomass production. However, maximum bio-yield (13.57 t ha-1) was given by S3 (boron), while the lowest (12.57 t ha^{-1}) was recorded in S1 (control). The study further expressed significant interactions between two factors. Maximum biomass (19.90 t ha^{-1}) was shown by M4S2 (green soil + 75% NPK + boron), which was followed by M4S2 (green soil + 75% NPK + zinc) and M4S1 (green soil + 75% NPK + control) with 18.60 and 17.06 t ha-1 biomass yield, correspondingly. Minimum bio-yield (7.23 t ha^{-1}) was noted in M1S1 (control). It was observed that assimilation of photosynthates become improved with adequate supply of nutrients, which is responsible for increasing biological yield. These results are in line with Aiyaz et al. (2015), while similar results had also been reported Kuntoji et al. (2021)

Harvest index

Results regarding harvest index are presented in (Table 4) showing non- significant effects of NPK, bio-fertilizer and micronutrients, as well as their interaction. The application of NPK and bio-fertilizer couldn't signify harvest index of maize. However, maximum index (35.89%) was recorded in M5 (green soil + 50% NPK), followed by M6 (green soil + 25% NPK) showing 35.22% harvest index. The least harvest index (29.56%) was shown by M3 (green soil). Highest index (34.37%) was received in S1 (control), while the least index (33.24%) was measured in S3 (boron). The two factors also interacted non-significantly with each other. However, maximum index (44.66 and 41.74%) was received in M5S1 (green soil + 50% NPK + control) and M6S2 (green soil + 25% NPK + zinc), correspondingly. The lowest harvest index (28.17 and 28.84%) was measured in M3S2 (green soil + zinc) and M3S1 (green soil + control), respectively. Non-significant indices might be due to adequate and appropriate fertilization of the crop, as well as using single germplasm that couldn't signify the results.

Benefit cost ratio

Economic analysis of maize crop as influenced by NPK, bio-fertilizer and micronutrients (Table 5) revealed significant variations regarding net returns as well as benefit cost ratio. The highest net return (Rs. 217,766/-) was received by the combined application of green soil and 75% NPK with boron (M4S3), followed by the same combination with zinc (M4S2) and control (M4S1) showing Rs. 206,556/- and Rs. 205,146/- return, respectively. The study further showed maximum benefit cost ratio (2.62) by applying green soil + 75% NPK + boron (M4S3), followed by M4S1 (green soil + 75% NPK + control) and M4S2 (green soil + 75% NPK + zinc) with 2.55 and 2.51 BCR, respectively. It was also observed that NPK application (at recommended rates) showed better return (Rs. 176,435/- and 171,655/-) recorded in M2S3 (RFD + boron) and M2S1 (RFD + control), respectively. The same showed 2.26 and 2.24 benefit cost ratio, correspondingly.

CONCLUSIONS

Based on the results of current study, it is concluded that the application of bio- fertilizer (green soil) in addition to 75% NPK rates and boron (M4S3) promoted growth of maize plants and enhanced the yield. Moreover, the study also showed beneficial growth status of plants by incorporating NPK alone (at recommended rates), but highest return followed by BCR was recorded for M4S3. Hence, it is recommended that for improved and higher grain yield of maize, bio-fertilizer (green soil) should be used in addition to NPK (75% of recommended rates) and boron under the agro-climatic environment of Dera Ismail Khan.

Supplementary materials

The supplementary material / supporting for this article can be found online and downloaded at: https://www.isisn.org/article/

Author contributions

Faheem Abbas: Conceptualization, methodology, investigation, data curation, writing—original draft preparation. Faheem Abbas conducted the experiments, collected and analyzed the data, and wrote the initial draft of the manuscript.

Muhammad Amjad Nadim: Supervision, project administration, writing—review and editing. Dr. Muhammad Amjad Nadim supervised the research work, provided guidance throughout the study, and contributed to the review and editing of the manuscript.

Muhammad Jawad Nazir: Resources, validation, formal analysis. Muhammad Jawad Nazir provided the necessary resources for the study, assisted in the validation of results, and performed formal data analysis.

Ehtesham Ul Haq: Resources, validation, formal analysis. Ehtesham Ul Haq assisted in providing resources, validating the results, and conducting formal data analysis.

Syed Muhammad Saqib Raza: Data curation, visualization, writing—review and editing. Syed Muhammad Saqib Raza helped in data curation, prepared visualizations, and contributed to reviewing and editing the manuscript.

Rashid Abbas: Investigation, data curation, writing—review and editing. Rashid Abbas contributed to the investigation, data collection, and provided input during the review and editing process.

Muhammad Ammar: Data curation, formal analysis, writing—review and editing. Muhammad Ammar was involved in data curation, formal data analysis, and reviewing and editing the manuscript.

Muhammad Nouman Malik: Methodology, software, validation. Muhammad Nouman Malik contributed to the development of the methodology, provided software support, and assisted in the validation of the study results.

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All of the data is primary

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Conflict of interest

The authors declared that present study was performed in absence of any conflict of interest.

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