VALUE ADDED FERTILIZERS AMELIORATE GRAIN YIELD AND NUTRITIONAL QUALITY OF MAIZE CROP

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ABSTRACT: A field trial was conducted to gauge the impact of value added NPK fertilizer, Zarkhez Plus, (N:08%;P:23%; K;18%) and biologically activated Zinc coated Urea (BAZU) maize. Treatments consisted; Control (T_1), Straight Fertilizers (DAP, MoP, Urea) (T_2), Zarkhez Plus + BAZU as 1/3rd replacement of Urea (T_3), Zarkhez Plus + BAZU as 2/3rd replacement of Urea (T_4), and Zarkhez Plus + BAZU as 1/3rd replacement of Urea (T_5). Results suggested that plant height, stem girth, rows cob^{-1}, grains row^{-1}, grains cob^{-1}, thousand seed weight were significantly improved by the application of Zarkhez Plus and BAZU. Grain yield was increased upto 30% with the application of Zarkhez Plus and BAZU compared to straight fertilizers. Application of BAZU beyond 1/3rd of the total N requirement did not increase the grain yield significantly but improved grain quality with higher Zn and K contents. Maize grain yield can be significantly increased with the application of Zerkhez Plus and replacing 1/3rd in-season N requirement with BAZU.

Keywords: Maize, Value-added Fertilizers, NPK fertilizer, BAZU, Nutrient uptake and Yield

(Received 29.10.2022 Accepted 29.01.2023)

INTRODUCTION

Maize *(Zea mays L.)* is a rich source of nutrients among cereals to meet up the nutritional requirements of both animal and humans, not only in context of Pakistan, but also globally (Ali *et al*., 2020). Maize is a rich source of energy and calories to the people living in urban and rural areas but also it is important for poultry and livestock industry in Pakistan (Sarwar *et al*., 2020). Scientists have been showing their concern regarding the low yield of Pakistan due to multiple factors including poor nutrition management to enhance maize productivity in Pakistan (Tariq and Iqbal, 2010). Nutrient management becomes of paramount important while considering the increase in yield and enhancement of nutritional quality (Lu *et al*., 2021).

There are many aspects that affect the maize crop yield but balanced nutrition of N, P & K with micronutrients especially Zinc plays an important role in developmental and growth stages of the maize crop. Burke *et al*. (2019) found that maximum profitable and cost-effective economical yield can only be obtained through the application of balanced well-adjusted adequate N, P and K fertilizer in maize, as Zinc increases the grain yield and grain nutrient contents when applied with balanced nutrients (Tariq *et al*., 2014; Anwar *et al*., 2021).

Application of inorganic fertilizer are essential to increase the crop productivity, but it is important to curb the losses of organic fertilizers. Value-added fertilizers with special coatings have become a special tool in recent time to enhance crop productivity. Improving Zinc fertilization can enhance grain zinc contents and ultimately help the mankind to get rid of, stunting, increased susceptibility to infectious diseases, poor birth outcomes and anemia in humans and enzymatic and metabolic activities improvement in plants (Suganya, Saravanan and Manivannan, 2020). Importance of Zinc increases many fold when it is linked with the uptake of macro nutrients like N, P & K. Intensive cropping resulted in mining of potassium from soils ultimately resulting in K deficiency so there is a high potential of increasing grains productivity through increasing the uptake of potassium (Rout *et al*., 2017).

Hussain *et al.* (2020) found increased potassium concentration in wheat grain when Zinc was applied as foliar spray, and also increased the grain yield. Application of zinc mitigates the salinity stress by increasing the potassium uptake in pepper plants resulting in higher levels of potassium in grains (Aktas *et al*., 2007). The K-induced gains in grain Zn concentration is attributed to K-driven higher post-anthesis Zn uptake and remobilization of pre-anthesis straw Zn store to grains (Naeem, Aslam and Lodhi, 2018). Sufficient amount of zinc when applied to cereals accelerates growth and developmental stages and the efficiency of micro-nutrients increases when applied in combination of nitrogen and Potash (Mekdad and Shaaban, 2020).

Biologically activated zinc coated over urea (42%N;1%Zn) also known as BAZU or Zabardast Urea, is a specialty fertilizer known to increase Zn uptake in grains (Ali, 2021). Although there have been several studies for impact of nutrition on maize yield and nutrient uptake in maize grain, but there is lacking information in dynamics of potassium uptake in relation to BAZU and NPK coated with Blend Coat (N:08%; P:23%; K;18%) marketed as Zarkhez Plus. Keeping in view of the systematic studies and facts of Potassium application with Zinc coated Urea fertilizer at different stages of maize crop for uptake of Zinc, a study was conducted to determine the effect of Potassium with Zinc coated Nitrogenous fertilizers on the growth performance of hybrid maize under irrigated conditions.

MATERIALS AND METHODS

This research work was carried out at the Research Area of Maize and Millet Research Institute Sahiwal (30.68^0N, 73.20^0E) during the spring season in the year 2021 and 2022. The experiment was laid out in randomized block design with three replications within the normal field area. The experimental soil (0-15 & 15-30 cm depth) was analyzed for initial soil physiochemical properties. Soil texture was Loam with 38% saturation having following properties: SAR 1.87, pH 8, EC 2.450 dSm^{-1}, available P_2O_5 6.67 ppm, available K_2O 155ppm, DTPA extractable Zn 1.083, Extractable Boron 0.493 and Sulphate 0.02% at 0-15 cm depth and at 15-30cm, SAR 1.933, pH 8, EC 2.880 dSm^{-1}, available P_2O_5 6.3ppm, available K_2O 176ppm. Spring maize hybrid evolved at MMRI (YH-5427) was used in both the seasons. Each experimental unit measured 4.2 m × 5 m, replicated thrice in randomized block design. Sowing was done on both sides of 1.05 m wider beds (furrow+top).

All the treatments except the control were balanced for 92kg/acre N; 46kg/acre P_2O_5; and 37Kg/acre K_2O, and the following treatment set was applied. Control (T1), Straight Fertilizers (DAP, MoP, Urea) (T2), Zarkhez Plus (N:08%; P_2O_5:23%; K_2O;18%) + BAZU as 1/3rd replacement of Urea (T3), Zarkhez Plus (N:08%; P_2O_5:23%; K_2O;18%) + BAZU as 2/3rd replacement of Urea (T4), and Zarkhez Plus (N:08%; P_2O_5:23%; K_2O;18%) + BAZU as 1/3rd replacement of Urea (T5) were used in RCBD design with three blocks. Phosphate fertilizer i.e., DAP (18:46), potassium fertilizer i.e., muriate of potash (KCl; 60%K_2O), and NPK (18:23:46) were applied manually prior to sowing and harrowed into the soil while Urea/BAZU were applied in three installments at 20, 30 and 45 days after sowing (DAS). In both years sowing was done during the second week of the February and crop was harvested on 2nd June and 8th June, in 2021 and 2022 respectivley, after the onset of physiological maturity.

All crop management and weed control measures was carried out by standard chemical and manual methods. The chlorophyll reading was taken with SPAD meter with fortnightly interval. During manual harvest, 30 cobs from each treatment were taken. The soil was extracted using the Mehlich III method. The crop was harvested at maturity. Post-harvest composite soil samples from each treatment per replication was taken with 0-15cm and 15-30cm depths and analyzed. The content of available Phosphorous (P) in the grain extract was determined calorimetrically and the content of available potassium (K), Available Zinc from grains were analyzed. Grain and straw yields were recorded and analyzed for N,P,K and Zn content by adopting standard procedure for calculating total nutrient uptake by maize. The data of both seasons was pooled and was analyzed for heterogeneity of variance but no such issue was detected hence two years mean is presented. Significance of treatment was tested by Analysis of Variance (ANOVA) technique while treatment means were separated by least significant difference test at $p<0.05$.

RESULTS

Plant Height: Different fertilizer treatments had significant effect on plant height (Table 1 and Fig.1). The plants fertilized with T_4 produced taller plants compared to rest of the treatments, however, there were non-signific differences between T_3, T_4, and T_5 for plant height at 30 DAS. Plant height was maximum in plants treated with T_4 (46.1 cm) followed by T_5 and T_4 with 46 cm plant height. Treatment T_2 followed T_3 with 45.1 cm taller plants, and the control treatment (T_1) plots produced shortest plants with 33.4 cm height. The plants at 60 DAS produced 194.8 cm height under T_4 followed by 193.7 cm (T_5), 192 cm (T_3), 191.2 cm (T_2) and 175.7 cm (T_1). Plants showed similar pattern of significance at 30 DAS, and 90 DAS. Tallest plants were found in T_4 (221.4 cm) followed by T_5 (220.5 cm), T_3 (218.2 cm), T_2 (217.4 cm), and 201.9 cm (T_1). The differences in plant heights were pronounced amongst the treatment throughout the crop cycle.

Stem Girth (cm): Stem Girth or thickness of the maize crop differ significantly since 30 DAS till the harvest of crop (Table 2, Fig.2). The plants fertilized with T_4 produced maximum thickness (1.52) followed by T_5 (1.51 cm), T_3 (1.43 cm), T_2 (1.40 cm), and T_1 (1.28 cm) at 30 DAS. Treatment T_4 significantly surpassed the T_5 at 60, and 90 DAS where T_4 produced the maximum stem girth. Thickness of stalk under T_4 increased to 2.05 cm at 60 DAS, followed by T_5 (1.97 cm), T_3 (1.94 cm), T_2 (1.91 cm) and T_1 (1.67 cm) at 60 DAS. The increase in stem thickness continued same pattern at 90 DAS when maximum 2.27 cm thick plant stalks were found in plants fertilized with T_4, followed by T_5 (2.25 cm), T_3 (2.23 cm), T_2 (2.22 cm) and T_1 (1.98 cm). There have been non-significant differences between T_4, and T_5 throughout the crop life cycle, whereas the differences among T_3 with T_4, and T_5 became significant at 90 DAS when the plants fertilized with T3 showed thinner stems than that of T_4, and T_5.

SPAD Values: The SPAD values showed increasing pattern through the maize crop cycle, except the control treatment that followed the decline in SPAD value after reaching the zenith at 60 DAS, contrary to the rest of the treatments which kept on increasing the SPAD value after 60 DAS and became constant at 75 and 90 DAS. The SPAD values of the plants fertilized with T_5 were superior to T_4 but statistically non-significant through the crop life cycle. The differences among T_4 and T_5 with T_3 and T_4 become significant at 60 DAS which remain significant till crop harvest. Treatments T_5 and T_4 were similar and superior to the rest of the treatment at the time of harvest.

Yield and Yield Components: The plants fertilized with T_3, T_4, and T_5 produced maximum (16) rows per cob followed by T_2 with 15 rows per cob. The plants fertilized with T1 produced minimum (13.33) rows per cob. T3 was statistically similar to T_4, and T_5 for rows per cob, but significantly different from them for the rest of the yield components and, ultimately for the yield as well. Number of grains per row and per cob were maximum under treatment T_5 (35.1, and 561 cm, respectively) followed by T_4 with 35 and 560 grains per row, and cob, respectively. Treatment T_4 was followed by T_3 with 33.83, and 541.33 grains per row and cob, respectively. T_3 produced 31.33 grains per row and resulted in 470 grains per cob. The minimum number of grains per row (10.5) and per cob (139.6) were observed in the control treatment (T1).

Average weight per cob was maximum under T_4, non-significantly followed by T_5 with 163.92 g, and 161.24 g, respectively. The differences became significant when T_4 was followed by T_3, T_2 and T_1 with 160.7 g, 139.87 g, and 62.78 g, respectively. Thousand seed weight (TSW) also followed the similar pattern of significance when the maximum (291.8 g) was observed in T_4, followed by T_5 (291.8 g), T_3 (290.9 g), T_2 (268.9 g) and T_1 (170 g).

Grain yield is the product of several yield components; therefore, it is obvious that the treatments showing significantly higher performance for yield components will show the similar for the ultimate grain yield as well. The plots fertilized with T_5 produced maximum grain yield (4816 kg/acre) non-significantly followed by T_4 (4907 kg/ac), T_3 (4724 kg/ac), T_2 (3791 kg/ac) and T_1 (714 kg/ac). The yield increment with respect to control treatment (T_1) was maximum for T_5 with 588.5 % increment, followed by T_4 (587.3 %), T_3 (561.7%), and T_2 (431%). Although the yield increase with Zabardast Urea treatment when applied for more than one time, but the yield become stagnant when applied for three times (T_5).

Nutrient Uptake in Grain: All the treatments were statistically significant form each other for grain zinc and potash contents, whereas T_3, T_4, and T_5 were statistically similar to each other for grain phosphorous contents. T_2 and T_1 were significantly different from other treatments for grain phosphorous contents (Table 4). Maximum Zin in grain (19.006 ppm) was found under treatment T_5, followed by T_4 (18.006 ppm), T_3 (16.005 ppm), T2(14.005 ppm), and T_1 (10.003 ppm). Similar pattern was observed for grain potassium content as T_5 resulted in maximum potash accumulation in grain (0.4%). Followed by T_4 (0.33%), T_3 (0.27%), T_2 (0.25%), and T_1 (0.210%). A strong positive correlation (r=0.92%) was observed between grain zinc uptake and grain potassium concentration with R^2= 0.846 (). The Zn content in grain predicts the potassium content in grain by the equation

$$K(\%) = -0.00152 + 0.0191 * \mathrm{Zn(ppm)}$$

Nutrient removal by the grains also indicates the pattern of significance similar to the grain nutrient status of maize fertilized with different treatments. The plants fertilized with T_5 accumulated maximum nutrients in grains for all the nutrients. Maximum Zinc uptake (93.532 g/ac) was observed in T_5, followed by T_4 (88.439 g/ac), T_3 (75.68 g/ac), T_2 (53.146 g/ac), and T_1 (7.149 g/acre). Likewise, maximum potassium uptake and removal for grains was observed for T_5 with 19.689 kg/ac potassium removal, followed by T_4 (16.214 Kg/ac), T_3 (12.771 Kg/ac), T_2 (9.490 Kg/ac) and T_1 (1.5 Kg/ac). Treatments T_3, T_4, and T_5 were statistically similar to each other for phosphorous removal for grain, but the rest of two treatments were non-significant. Maximum phosphorous uptake for grain was observed for T_5 (28.549 Kg/ac), followed by (28.498 Kg/ac), T_3 (26.488 Kg/ac), T_2 (19.740 Kg/ac), and T_1 (2.145 Kg/ac). Increasing the amount of Zabardast urea as a source of nitrogen, also increased the Zn contents in maize grain, and ultimately potassium and phosphorous contents also increased. However, the total grain yield did not increase when additional Zabardast urea was applied for more than two instances.

Table 1: Plant Height (cm) of the Maize Crop at different days after sowing (DAS) as affected by different fertilizer treatments.

Treatment	30 DAS				60 DAS				90 DAS			
T1	33.4	±	0.203	c	175.7	±	0.651	c	201.9	±	2.74254	c
T2	45.1	±	0.273	b	191.2	±	0.458	b	217.4	±	0.69284	b
T3	46.0	±	0.338	ab	192.0	±	0.273	b	218.2	±	0.4631	ab
T4	46.1	±	0.384	a	194.8	±	0.393	a	221.4	±	0.53646	a
T5	46.0	±	0.384	ab	193.7	±	0.907	a	220.5	±	0.36057	ab

Table 2: Stem Girth (cm) of the Maize crop as affected by different fertilizer treatments.

Treatment	30 DAS				60 DAS				90 DAS			
T1	1.28	±	0.009	c	1.67	±	0.081	c	1.98	±	0.021	d
T2	1.40	±	0.003	b	1.91	±	0.01	b	2.22	±	0.003	c
T3	1.43	±	0.003	ab	1.94	±	0.003	ab	2.23	±	0.006	bc
T4	1.52	±	0.025	a	2.05	±	0.023	a	2.27	±	0.01	a
T5	1.51	±	0.028	a	1.97	±	0.006	ab	2.25	±	0.01	ab

Table 3: Yield and Yield Components of Maize crop as affected by different fertilizer treatments.

Treatments	Rows per cob			Number of Grains Per Row			No of Grains per Cob			Average Weight per Cob (g)			Thousand Seed Weight (g)			Grain Yield (kg/Acre)		
T1	13.33	±	0.11[c]	10.50	±	0.18[d]	139.96	±	2.42[d]	62.78	±	1.09[d]	170.00	±	2.94[d]	714.00	±	12.37[d]
T2	15.00	±	0.00[b]	31.33	±	0.54[c]	470.00	±	8.14[c]	139.87	±	2.42[c]	268.90	±	4.66[c]	3791.49	±	65.67[c]
T3	16.00	±	0.00[a]	33.83	±	0.59[b]	541.33	±	9.38[b]	160.70	±	2.78[b]	290.90	±	5.04[b]	4724.20	±	81.83[b]
T4	16.00	±	0.00[a]	35.00	±	0.61[a]	560.00	±	9.70[a]	163.92	±	2.84[a]	292.10	±	5.06[a]	4907.28	±	85.00[a]
T5	16.00	±	0.00[a]	35.10	±	0.61[a]	561.60	±	9.73[a]	161.24	±	2.79[a]	291.80	±	5.05[a]	4916.24	±	85.15[a]

Table 4: Grain nutrient status of the maize crop as affected by different fertilizer treatments.

Treatments	Zinc (ppm)			K (%)			P (%)		
T1	10.003	±	0.257e	0.210	±	0.005e	0.300	±	0.008c
T2	14.005	±	0.360d	0.250	±	0.006d	0.520	±	0.013b
T3	16.005	±	0.412c	0.270	±	0.007c	0.560	±	0.014a
T4	18.006	±	0.463b	0.330	±	0.008b	0.580	±	0.015a
T5	19.006	±	0.489a	0.400	±	0.010a	0.580	±	0.015a

Table 5: Nutrient removal by maize grains as affected by different fertilizer treatments.

Treatments	Zinc Uptake in Grain (g/ac)			K Uptake in Grain (Kg/ac)			P Uptake in Grain (Kg/ac)		
T1	7.149	±	0.307e	1.501	±	0.065e	2.145	±	0.092c
T2	53.146	±	2.284d	9.490	±	0.408d	19.740	±	0.848b
T3	75.680	±	3.252c	12.771	±	0.549c	26.488	±	1.138a
T4	88.439	±	3.800b	16.214	±	0.697b	28.497	±	1.225a
T5	93.523	±	4.019a	19.689	±	0.846a	28.549	±	1.227a

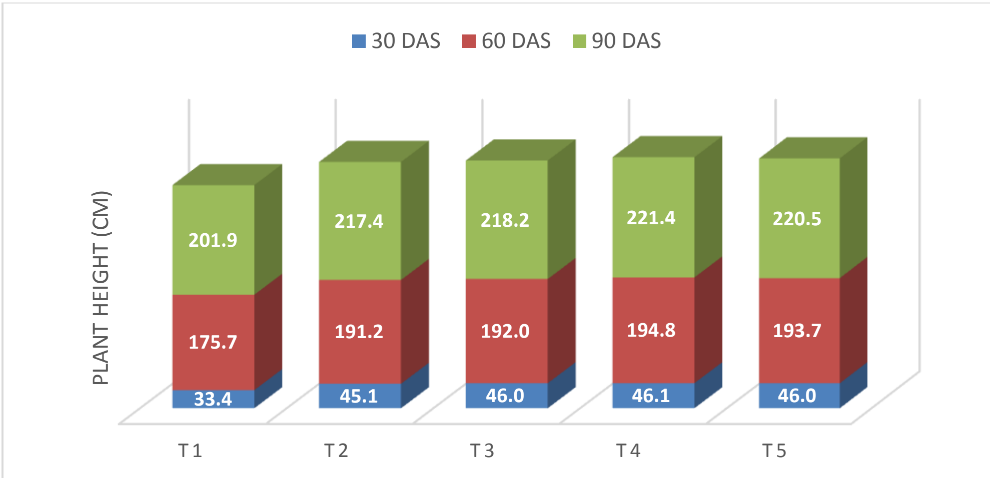

Figure 1: Plant Height (cm) of maize crop as affected by different fertilizer treatments

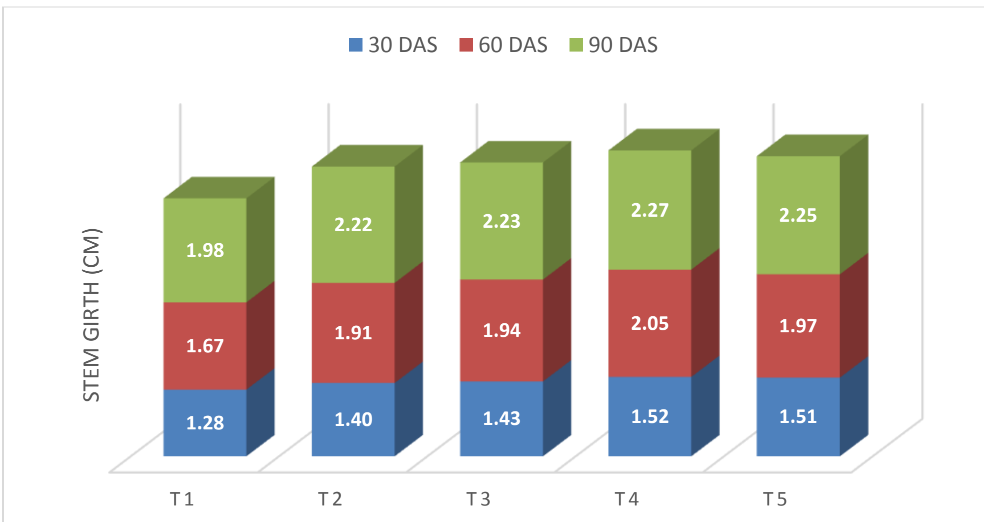

Figure 2: Stem Girth of maize crop as affected by different fertilizer treatments

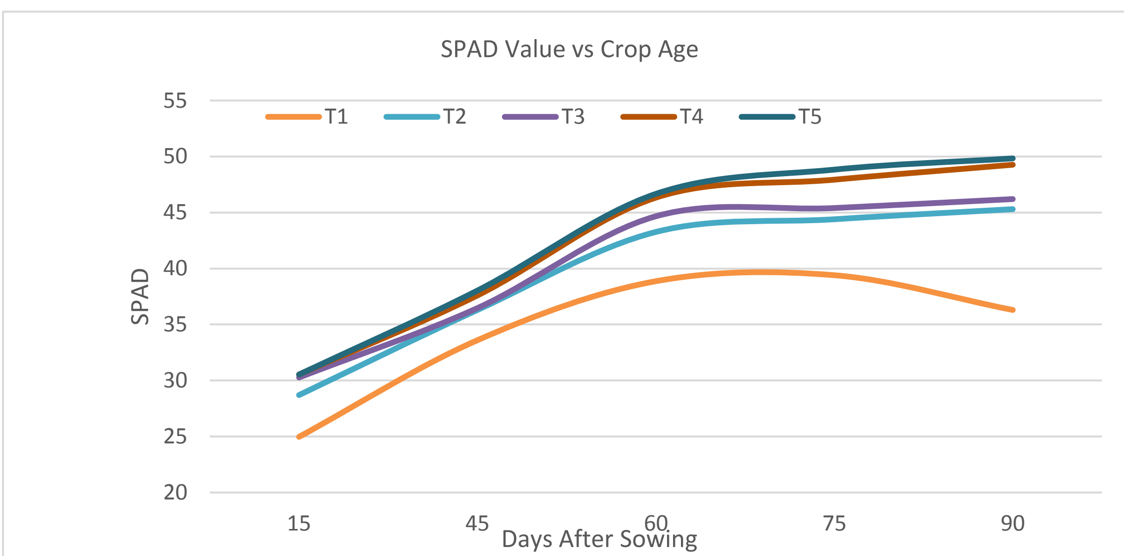

Figure 3: SPAD values of maize crop at different days after sowing as affected by different fertilizer treatments.

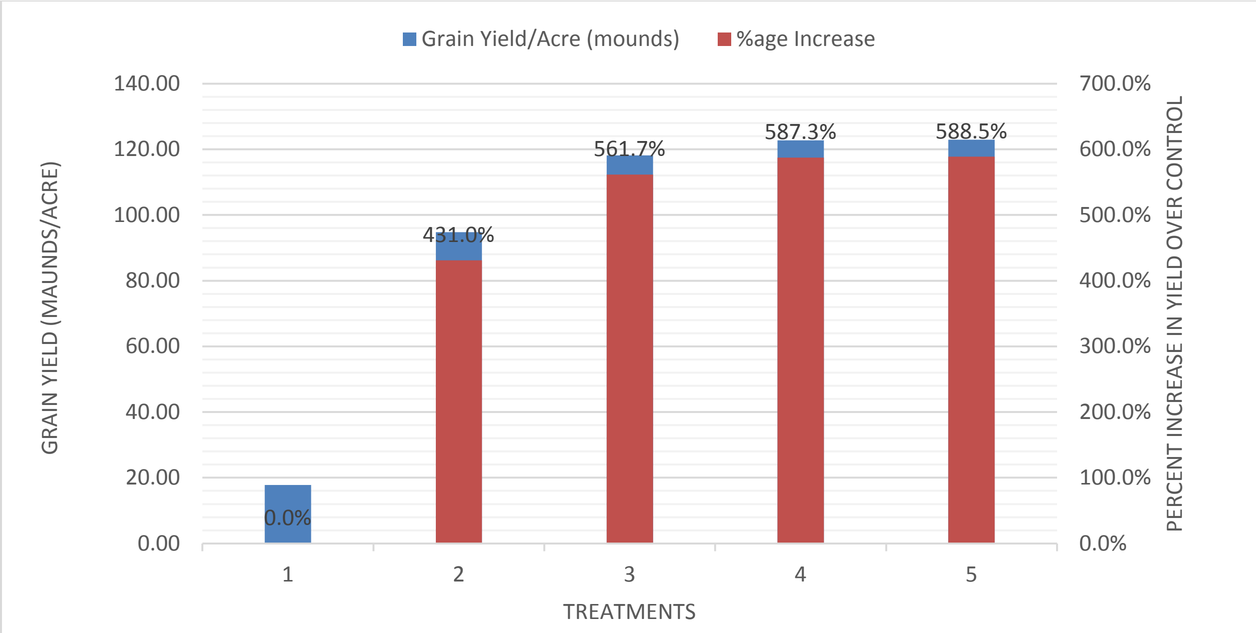

Figure 4 Percentage increase of grain yield over control as affected by different fertilizers

DISCUSSION

The results indicated that the application of fertilizers enhance the plant height and stem girth, and value-added fertilizers increase the plant height and thickness. It is also clear that application of enhanced rates of BAZU (2/3rd and whole replacement) produced maximum heights at silking to grain filling stage (60 DAS), but the increment in the heights become non-significant by increasing the amount of BAZU from 1/3rd to further. Furthermore, a decline in stem thickness by increasing the BAZU from 2/3rd (T4) to 3/3rd (T5) indicated the less involvement of Zn in increasing the stem thickness and more towards other functions including, grain formation and quality enhancement.

SPAD value increased over the time for all treatments except the control treatment that decreased after reaching at peak at the time of silking. The increasing SPAD value with the application of value-added fertilizer indicate the increased uptake of nitrogen, as Reyes, Correa, and Zuniga (2017) predicted higher nitrogen concentrations with higher SPAD values. The result supported the hypothesis that the value-added fertilizers (T_3, T_4, and T_5) improved the grain yield, but it is also evident from the results that replacing the 1/3rd plain urea with BAZU in presence of Zarkhez plus (T_3), increased the yield, which further increased when the amount of BAZU was increased to 2/3rd of the total urea requirement (T_4). The increase in yield halted with further increase in BAZU when the plain urea was completely replaced with BAZU (T_5). Fertilization with Zarkhez Plus and BAZU enhanced the number of rows per cob, but it reaches its potential with single application (1/3rd) of BAZU (T_3) and thus further fertilization with BAZU did not increase the number of rows per cob. Other yield components including the thousand seed weight, number of grains per row and per cob also increased with application of value-added fertilizers but increasing the application of BAZU from 1/3rd to 2/3rd improved the yield components and grain yield but further increase in the amount of BAZU did not improve any of the yield component. Coating of the Akhter *et al.* (2021) also found that the application of coated NPK fertilizer enhances the grain yield of maize crop. Bordoloi, Baruah and Hazarika (2020) also found advantage of coated urea over plain urea and uncoated NPK fertilizer in terms of curbing nutrient losses and ultimately increasing the yield. Therefore, the increased yield in our study due to application of value-added fertilizer may be attributed to the decrease in nutrient losses and more availability for plants for uptake. Fertilization of Zn enhances the number of grains per cob because the Zn plays a positive role in pollen tube development and chance of filled grains increase with the application of Zinc (Khalafi *et al.*, 2021).

The quality of grain improved with the application of fertilizers, and the application of combination of Zarkhez plus and Zabardast Urea or BAZU increased the grain Zn, Potash and phosphorous concentrations and total nutrient removal for grain. Ain *et al.* (2020) also found that the application Bacillus-Augmented Zinc Oxide (BAZ) increases the uptake of potassium, and zinc in wheat plants and provide the plants more fighting chance against the salinity. The higher amounts of BAZU resulted in higher grain Zn and potash concentration though the phosphorous concentration insignificantly increased when the amount of BAZU applied was increased. Likewise, the yield increment was recorded in the presence of BAZU possibly due to the higher Zn uptake and beneficial effects of microbes present in BAZU, but the further yield enhancement from increasing BAZU from 2/3rd to whole, could not increase the yield because of the yield potential of the maize hybrid used for experimentation, but quality of the produce increased with each increment of the BAZU. The increment of the potassium content in grain with linked with the increase in grain zinc content as it showed a positive association between them, but the phosphorous concentration could not increase significantly at the same rate, indicating its varied response and nutrient affiliation.

Conclusion: The application of value-added fertilizers, Zarkhez Plus (N:08%;P:23%; K;18%) and biologically active zinc coated Urea (BAZU) increased the yield upto 30% compared to conventional straight fertilizers i.e., DAP, MoP, and Urea. Application of Zarkhez Plus and alongwith replacement of 1/3rd replacement of conventional Urea with BAZU enhanced the yield significantly, however further further increment in BAZU (2/3rd replacement) did not increased grain yield but significantly improved uptake of zinc and potash in grain to increase the nutritional quality of the produce. Therefore, it is recommended that under irrigated condition of Punjab, both the value-added fertilizers Zarkhez Plus and BAZU should be applied as a fertilizer choice to enhance hybrid maize yield and grain quality.

Acknowledgements: The authors are thankful for the support of Muhammad Tariq and Lab staff for grain analyses, and Muhammad Tayyab, Muhammad Mubin Javed, and field staff of MMRI for their on-field support.

REFERENCES

Ain, N.U., M. Naveed, A. Hussain, M.Z. Mumtaz, M.A. Rafique, S. Bashir, S. Alamri and M.H. Siddiqui (2020). Impact of coating of urea with Bacillus-augmented zinc oxide on wheat grown under salinity stress. Plants. 9: 1375. https://doi.org/10.3390/plants9101375.

Aktaş, H., K. Abak, L. Öztürk and I. Çakmak (2007). The effect of zinc on growth and shoot concentrations of sodium and potassium in pepper plants under salinity stress. Turk. J. Agri. Forest. 30: 407-412.

Akhter, M., G.A. Shah, M.B.K. Niazi, S. Mir, Z. Jahan and M.I. Rashid (2021). Novel water- soluble polymer coatings control NPK release rate, improve soil quality and maize productivity. J. App. Polymer Sci. 138: 51239

Ali, A., M. Adnan, A. Abbas, M.A. Javed, M.E. Safdar, M. Asif, M. Imran, T. Iqbal, F. Rehman and R. Ahmad R (2020). Comparative performance of various maize (Zea mays L.) cultivars for yield and related attributes under semi-arid environment. Agri. Biol. Res. 36(4): 63-66.

Ali, M.A., F. Naeem, N. Tariq, I. Ahmad and A. Imran (2021) Bioactive Nutrient Fortified Fertilizer (BNFF); a novel hybrid approach for the enrichment of wheat grain with Zinc. Front. Plant. Sci. 12:743378.

Anwar, Z., Z. Basharat, M.B. Hafeez, S. Khan, N. Zahra, Z. Rafique and M. Maqsood (2021). Biofortification of maize with zinc and iron not only enhances crop growth but also improves grain quality. Asian J. Agric. Biol. 8: 332-339.

Burke, W.J., E. Frossard, S. Kabwe and T.S. Jayne (2019). Understanding fertilizer adoption and effectiveness on maize in Zambia. Food Policy, 86: 101721.

Cakmak, I., W.H. Pfeiffer and B. McClafferty (2010). Biofortification of durum wheat with zinc and iron. Cereal Chem. 87: 10-20.

Hussain, S., M.A. Shah, A.M. Khan, F. Ahmad and M. Hussain (2020). Potassium enhanced grain zinc accumulation in wheat grown on a calcareous saline-sodic soil. Pak. J. Bot. 52: 69-74.

Khalafi, A., K. Mohsenifar, A. Gholami and M. Barzegari (2021). Corn (*Zea mays* L.) growth, yield and nutritional properties affected by fertilization methods and micronutrient use. Int. J. Pl. Prod. 15: 589-597.

Lu, J., T. Hu, B. Zhang, L. Wang, S. Yang, J. Fan, S. Yan and F. Zhang (2021). Nitrogen fertilizer management effects on soil nitrate leaching, grain yield and economic benefit of summer maize in Northwest China. Agri. Water Manag. 247(C):106739.

Mekdad, A.A.A and A. Shaaban (2020). Integrative applications of nitrogen, zinc, and boron to nutrients-deficient soil improves sugar beet productivity and technological sugar contents under semi-arid conditions. J. Pl. Nutrition 43: 1935-1950.

Naeem, A, M. Aslam and A. Lodhi (2018). Improved potassium nutrition retrieves phosphorus-induced decrease in zinc uptake and grain zinc concentration of wheat. J. Sci. Food Agri. 98: 4351-4356.

Reyes, J.F., C. Correa and J. Zuniga (2017). Reliability of different color spaces to estimate nitrogen SPAD values in maize. Comput. Electron. Agri. 143: 14-22

Rout, P.P., N. Chandrasekaran, S. Arulmozhiselvan and D. Padhan, 2017. Effect of long term fertilization on soil K dynamics and uptake by hybrid maize in an irrigated Inceptisol under intensive cropping. Int. J. Current Microbiol. Appl. Sci. 6: 1049-1061.

Sarwar, N., O. Farooq, A. Wasaya, M. Hussain, A.M. El-Shehawi, S. Ahmad, M. Brestic, S.F. Mahmoud, M.Zivcak, S. Farooq (2021). Integrated nitrogen management improves productivity and economic returns of wheat-maize cropping system. J. King Saud Univ.-Sci. 33(5): 101475.

Suganya, A., A. Saravanan and N. Manivannan (2020). Role of zinc nutrition for increasing zinc availability, uptake, yield, and quality of maize (*Zea mays* L.) grains: An overview. Commun. Soil Sci. Pl. Anal. 51: 2001-2021.

Tariq, A., S.A. Anjum, M.A. Randhawa, E. Ullah, M. Naeem, R. Qamar, U. Ashraf and M. Nadeem , 2014. Influence of zinc nutrition on growth and yield behaviour of maize (*Zea mays* L.) hybrids. Amer. J. Pl. Sci. 5(18):2646-2654.

Tariq M and H. Iqbal (2010). Maize in Pakistan–an overview. Agri. Natural Res. 44: 757-763.