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Assessment of Post-Harvest Soil Macro and Micronutrient Content Under Nutrient Omission Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was carried out at the Main Maize Research Station, Anand Agricultural University, Godhra, Gujarat during two successive *kharif* seasons in 2022 and 2023 to evaluate the impact of nutrient omission on the nutrient status of soil after harvest of maize. Evaluating soil fertility is essential for ensuring adequate and balanced fertilization for high crop productivity. A nutrient omission trial helps identify the most limiting nutrients for crop growth. If a particular nutrient is excluded while all others are supplied at appropriate levels and the plants exhibit poor growth, the omitted nutrient is considered a limiting factor. On the other hand, if a nutrient is omitted but plant growth remains healthy, then that nutrient is not a limiting factor for crop production. The study was

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designed using a Randomized Block Design (RBD) with three replications and included fourteen different nutrient omission treatments: control (T_1), 160 kg N ha^{-1} (T_2), 20 kg P_2O_5 kg ha^{-1} (T_3), $N_{160}P_{20}$ kg ha^{-1} (RDF) (T_4), $N_{160}P_{20}K_{60}$kg ha^{-1} (T_5), $N_{160}P_{20}S_{20}$ kg ha^{-1} (T_6), $N_{160}P_{20}Zn_5$ kg ha^{-1} (T_7), $N_{160}P_{20}Fe_{10}$kg ha^{-1}(T_8), $N_{160}P_{20}K_{60}S_{20}$ kg ha^{-1}(T_9), $N_{160}P_{20}K_{60}Zn_5$kg ha^{-1}(T_{10}), $N_{160}P_{20}K_{60}Fe_{10}$ kg ha^{-1} (T_{11}), $N_{160}P_{20}K_{60}S_{20}Zn_5$kg ha^{-1} ($T_{12}$), $N_{160}P_{20}K_{60}S_{20}Fe_{10}$kg ha^{-1} ($T_{13}$) and $N_{160}P_{20}K_{60}S_{20}Zn_5Fe_{10}$ kg ha^{-1} (T_{14}). The maize hybrid GAWMH 2 was cultivated for both *kharif* seasons to assess treatment effects. The organic carbon, soil EC, pH, DTPA-Mn and Cu did not exhibit significant influence by different nutrient omission treatments during both years 2022 and 2023. Among the different treatments studied, significantly higher available nitrogen (239 and 245 kg ha^{-1}), phosphorus (51.84 and 53.50 kg ha^{-1}), potassium (252 and 254 kg ha^{-1}) and sulphur (10.59 and 10.70 mg kg^{-1}) in soil after harvesting of maize was observed under the application of T_{14} ($N_{160}P_{20}K_{60}S_{20}Zn_5Fe_{10}$ kg ha^{-1}) treatment during both the year. While, lower content (195, 193, 42.41, 41.16, 217, 213 kg ha^{-1}, 8.55 and 8.30 mg kg^{-1}) was observed with control treatment (T_1) during 2022 and 2023. Throughout both years of the study, there was a noticeable improvement in the soil's available nitrogen, phosphorus, and potassium compared to the initial levels. In 2022, nitrogen levels increased by 14.90%, followed by a 17.78% rise in 2023. Phosphorus availability also improved, showing a 12.69% increase in 2022 and 16.30% in 2023. Likewise, available potassium rose by 7.23% in 2022 and 8.06% in 2023 relative to the initial soil nutrient content. Nutrient omission treatments did not significantly affect the available zinc and iron contents in the soil after maize harvest in 2022. However, in 2023, available zinc and iron were significantly higher in treatment T_{14} while the lowest zinc and iron content observed in the control treatment (T_1).

Keywords: Maize; nitrogen; omission plot; phosphorous; potassium; micronutrient.

1. INTRODUCTION

Maize (*Zea mays* L.) is a prominent cereal crop valued for its high productivity and adaptability to diverse environmental conditions and Considerable role in both and human and animal diets, making it known as the "Queen of Cereals". It serves dual purposes as both food and animal feed, in addition to being an important raw material for industries producing protein, starch, oil, pharmaceuticals, sweeteners, alcoholic beverages, cosmetics, and biofuels. Maize is nutritionally rich, comprising approximately 70% carbohydrates, 10% protein, and 4% oil (Jat *et al.*, 2019). Therefore, this crop holds significant potential to combat hunger and contribute to food and nutritional security (Grote *et al.*, 2021). Maize is important not only because of its excellent adaptability to a wide range of conditions but also due to its strong responsiveness to enhanced management practices, particularly irrigation and fertilization. In India, maize ranks third in importance among cereals, after rice and wheat (Suganya *et al.*, 2020; Mahapatra *et al.*, 2018). Globally, maize was grown on 208.23 million hectares, producing 124 million tonnes with an average productivity of 5.96 t ha^{-1} (FAOSTAT, 2023). In India, maize cultivation covered 11.24 million hectares, with a production of 37.67 million tonnes and an average yield of 3351 kg ha^{-1} (Anonymous, 2023). In Gujarat state during 2023-24, maize was cultivated on 4.05 lakh hectares, yielding 9.09 million tonnes with an average productivity of 2244 kg ha^{-1} (Anonymous, 2023).

Nitrogen is crucial for plant growth, development, and chlorophyll formation, acting as a fundamental component of protoplasm and chlorophyll, essential for all living cells. Phosphorus is vital for plant metabolism, energy transfer (ADP/ATP), and genetic inheritance (RNA/DNA), supporting the growth of all living organisms. Potassium maintains cellular structure, regulates water balance, activates enzymes for protein and carbohydrate metabolism, aids carbohydrate translocation, and boosts disease resistance (Rajanna *et al.*, 2006). Sulphur is primarily known for its role in amino acid and protein synthesis, chlorophyll formation, and enhancing nitrogen fixation in legumes and oil content in oilseeds. Zinc deficiency is a widespread global issue. This micronutrient is key to enzyme activity (carbonic anhydrase, alcohol dehydrogenase, superoxide dismutase), chlorophyll and protein synthesis, water absorption regulation, and the synthesis of important plant hormones (indole acetic acid, gibberellic acid) and RNA in legumes. Iron, an essential micronutrient, is critical for electron transfer in photosynthesis, respiration, nitrogen fixation, and DNA synthesis, making it vital for capturing and utilizing light energy.

To maximize maize yield, adequate and balanced fertilization is essential, especially since maize hybrids demonstrate a strong response to added nutrients. This is crucial because current fertilizer recommendations tend to be generalized, primarily focusing on nitrogen, phosphorus, and potassium, rather than providing targeted, site-specific nutrient management (Singh *et al.*, 2020). The omission plot technique is a straightforward and effective method for optimizing fertilizer plans. It involves establishing small plots, each receiving all essential nutrients except for one specific nutrient, which is intentionally excluded. By comparing the yield of these "omission" plots to a fully fertilized control plot at the end of the growing season, it can be determined which nutrients are deficient and significantly limiting crop production. If a plot missing a nutrient yields similarly to the full treatment, that nutrient is sufficiently available in the soil. A lower yield in an omission plot, however, signals a need for additional fertilization of that nutrient. Once limiting nutrients are identified, further research can determine optimal application rates. This technique, as highlighted by Singh *et al.* (2008), is a precision nutrient management approach that correlates grain yield with the soil's natural nutrient supply to boost crop productivity, primarily by assessing the soil's intrinsic capacity to supply the omitted nutrient.

2. MATERIALS AND METHODS

A field experiment was conducted over two consecutive *kharif* seasons (2022 and 2023) at the Main Maize Research Station, Anand Agricultural University, Godhra, Gujarat, India. Maize variety GAWMH 2 was used for this study. The experimental site, situated at an elevation of 157 meters above mean sea level (22°47'N latitude, 73°39'E longitude), experienced average maximum temperatures between 21.5°C and 28.5°C during the crop's growth. A total of 579 mm and 1365 mm of rainfall was recorded during *kharif* 2022 and 2023. The soil of the experimental field having loamy sand texture with the pH of 7.67, soluble salts (EC: 0.24 dS m^{-1}), low organic carbon content (0.43%), and 208, 46, 235 and 8.76 kg ha^{-1} N, P, K and S respectively analyzed by following Walkley and Black (1934) for organic carbon, alkaline $KMNO_4$ method Subbiah and Asija (1956) for available nitrogen, Olsen *et al.* (1954)for available phosphorus, 1M NH_4OAc (ammonium acetate), pH 7.0 extraction for available potassium and available sulphur by extracting the soil with 0.15 per cent $CaCl_2$ solution and determined colorimetrically by Williams and Steinbergs(1959). Micronutrients content were medium in case of Zn (0.88 ppm) and Fe (5.90 ppm), high in case of Mn (11.15 ppm) and Cu (1.41 ppm) in soil analyzed by DTPA extraction method in the top 15 cm of soil. The experiment was laid out in randomized block design with three replications.

Nitrogen, phosphorus, potassium, sulfur, zinc, and iron were supplied using urea, DAP/orthophosphoric acid, muriate of potash, bentonite, zinc chloride and iron chloride, respectively. The recommended nitrogen dose was split into four equal applications: basal, 4th leaf stage, 8th leaf stage and tasseling stage. All other recommended nutrients (phosphorus, potassium, sulfur, zinc and iron) were applied as basal at time of sowing. Plots measured 5 m x 3.6 m, with maize seeds sown at 60 cm x 20 cm spacing.

Table 1. Total nutrients applied to maize crops during both years

Treatment no	Treatment	Nutrient applied (kg ha^{-1})					
		N	P	K	S	Zn	Fe
T_1	Control	-	-	-	-	-	-
T_2	$N_{160}P_0K_0S_0Zn_0Fe_0$	160	-	-	-	-	-
T_3	$N_0P_{20}K_0S_0Zn_0Fe_0$	-	20	-	-	-	-
T_4	$N_{160}P_{20}K_0S_0Zn_0Fe_0$	160	20	-	-	-	-
T_5	$N_{160}P_{20}K_{60}S_0Zn_0Fe_0$	160	20	60	-	-	-
T_6	$N_{160}P_{20}K_0S_{20}Zn_0Fe_0$	160	20	-	20	-	-
T_7	$N_{160}P_{20}K_0S_0Zn_5Fe_0$	160	20	-	-	5	-
T_8	$N_{160}P_{20}K_0S_0Zn_0Fe_{10}$	160	20	-	-	-	10
T_9	$N_{160}P_{20}K_{60}S_{20}Zn_0Fe_0$	160	20	60	20	-	-
T_{10}	$N_{160}P_{20}K_{60}S_0Zn_5Fe_0$	160	20	60	-	5	-
T_{11}	$N_{160}P_{20}K_{60}S_0Zn_0Fe_{10}$	160	20	60	-	-	10
T_{12}	$N_{160}P_{20}K_{60}S_{20}Zn_5Fe_0$	160	20	60	20	5	-
T_{13}	$N_{160}P_{20}K_{60}S_{20}Zn_0Fe_{10}$	160	20	60	20	-	10
T_{14}	$N_{160}P_{20}K_{60}S_{20}Zn_5Fe_{10}$	160	20	60	20	5	10

3. RESULTS AND DISCUSSION

3.1 Effect on EC, pH and OC After Harvest of Maize

The result in Table.2 revealed that nutrient omission treatments on pH, EC and organic carbon after harvest of crop failed to show their significant influence during both the years.

3.2 Effect on Available N, P, K and S After Harvest of Maize

The result presented in Table 3 indicated that among the different treatments studied significantly higher available nitrogen in soil after harvesting of maize (239 and 245 kg ha^{-1}) was observed under the application of T_{14} treatment during individual year and it was par with T_{12}, T_{13}, T_9, T_{10}, T_{11}, T_5, T_8, T_7, T_6 and T_4 treatments, respectively. Micronutrient omission treatments (T_{12} and T_{13}) also exhibited elevated soil nitrogen levels, similar to T_{14}, possibly due to enhanced nutrient cycling and increased root efficiency. The observed significant differences indicate that balanced nutrient application plays a crucial role in improving nitrogen retention in the soil. Significant lower available nitrogen (195 and 193 kg ha^{-1}) in soil observed with control treatment (T_1) during 2022 and 2023. The similar findings were reported by Dai *et al.*, (2013) and Adhikari *et al.* (2014). Significantly higher available phosphorus in soil after harvesting of maize (51.84 and 53.50 kg ha^{-1}) was observed under the application of T_{14} during individual year and it was par with T_{12}, T_{13}, T_9, T_{11}, T_6, T_7, T_8, T_5, T_{10} and T_4 treatments. The availability of phosphorus was enhanced with the application of N, K, S, Zn and Fe, possibly due to positive interactions among these nutrients. Significant lower available phosphorus (42.41 and 41.16 kg ha^{-1}) in soil observed with control treatment (T_1) during individual year. These results are in the line of study reported by Prajapati *et al.* (2018) and Ray *et al.* (2020). The higher available potassium in soil after harvesting of maize (252 and 254 kg ha^{-1}) was observed under the application of T_{14} treatment during both the year. The treatments T_{12}, T_{13}, T_9, T_{10}, T_{11} and T_5, which received potassium at 60 kg ha^{-1}, were statistically at par with T_{14}. Significant lower available potassium (217 and 213 kg ha^{-1}) in soil observed with control treatment (T_1) during individual year. Similar results have also been reported by Lalfakzuali and Sharma (2021) and Rani and John (2022). Higher available sulphur in soil after harvesting of maize (10.59 and 10.70 mg kg^{-1}) was observed under the application of T_{14} treatment during individual year, respectively and it was par with T_{13}, T_9, T_{12} and T_6 treatment. Sulphur fertilization (20 kg ha^{-1}) improved soil available sulphur in soil. Significant lower available sulphur (8.55 and 8.30 mg kg^{-1}) in soil observed with control treatment (T_1) during individual year. A similar finding was also obtained by Mandal *et al.* (2022).

3.3 Effect on Available Zinc, Iron, Manganese and Copper after Harvest of Maize

Nutrient omission treatments did not significantly affect the available zinc and iron content in the soil after maize harvest during 2022 (Table 4). In 2023, available zinc levels were significantly higher in treatment T_{14} (0.94 mg kg^{-1}). It was statistically similar to T_{12}, T_{10} and T_7 treatments which received zinc applications and showed a comparable impact on soil zinc availability. The lowest available zinc (0.73 mg kg^{-1}) was observed in the control treatment (T_1). Similar results have also been reported by Prajapati *et al.* (2018) and Lalfakzuali and Sharma (2021). However, in 2023, the available iron was significantly higher in treatment T_{14}, followed by T_{13}, T_{11} and T_8 treatments indicating that iron-treated plots indicated a similar effect on soil iron availability. The lowest available iron was observed in the control treatment, T_1.The available manganese and copper after harvest of maize crop (Table 4) did not exert any significantly differences in nutrient omission treatments during the individual years. Balanced nutrient application enhanced the availability of nutrients in the soil after harvest. In contrast, plots where nutrients were omitted or left unfertilized showed a reduction in available nutrient levels. This could be attributed to increased nutrient uptake in plots receiving balanced fertilization compared to the control. These results are in agreement with the findings of Tripathi *et al.* (2018) and Singh *et al.* (2021).

Table 2. Effect of nutrient omission on EC after harvest of maize

Treatment No.	Treatments	EC (dS m^{-1})		pH		OC (%)	
		2022	2023	2022	2023	2022	2023
T_1	Control	0.26	0.27	7.60	7.59	0.37	0.37
T_2	$N_{160}P_0K_0S_0Zn_0Fe_0$	0.25	0.28	7.63	7.64	0.37	0.38
T_3	$N_0P_{20}K_0S_0Zn_0Fe_0$	0.28	0.28	7.63	7.59	0.38	0.38
T_4	$N_{160}P_{20}K_0S_0Zn_0Fe_0$	0.27	0.27	7.66	7.67	0.39	0.38
T_5	$N_{160}P_{20}K_{60}S_0Zn_0Fe_0$	0.27	0.27	7.69	7.76	0.39	0.38
T_6	$N_{160}P_{20}K_0S_{20}Zn_0Fe_0$	0.28	0.27	7.65	7.70	0.38	0.38
T_7	$N_{160}P_{20}K_0S_0Zn_5Fe_0$	0.25	0.27	7.67	7.66	0.37	0.38
T_8	$N_{160}P_{20}K_0S_0Zn_0Fe_{10}$	0.27	0.27	7.67	7.74	0.40	0.40
T_9	$N_{160}P_{20}K_{60}S_{20}Zn_0Fe_0$	0.27	0.27	7.66	7.72	0.38	0.37
T_{10}	$N_{160}P_{20}K_{60}S_0Zn_5Fe_0$	0.27	0.27	7.69	7.75	0.39	0.38
T_{11}	$N_{160}P_{20}K_{60}S_0Zn_0Fe_{10}$	0.28	0.28	7.68	7.75	0.40	0.38
T_{12}	$N_{160}P_{20}K_{60}S_{20}Zn_5Fe_0$	0.28	0.26	7.76	7.75	0.41	0.39
T_{13}	$N_{160}P_{20}K_{60}S_{20}Zn_0Fe_{10}$	0.27	0.28	7.75	7.77	0.42	0.40
T_{14}	$N_{160}P_{20}K_{60}S_{20}Zn_5Fe_{10}$	0.27	0.27	7.73	7.76	0.40	0.39
S. Em±		0.01	0.01	0.15	0.18	0.01	0.01
C. D. at 5 %		NS	NS	NS	NS	NS	NS
C.V.%		4.16	4.03	3.28	4.05	4.97	5.89

Table 3. Effect of nutrient omission on available N, P, K and S after harvest of maize

Treatment No.	Treatments	Available N (Kg ha^{-1})		Available P (Kg ha^{-1})		Available K (Kg ha^{-1})		Available S (mg kg^{-1})	
		2022	2023	2022	2023	2022	2023	2022	2023
T_1	Control	195	193	42.41	41.16	217	213	8.55	8.30
T_2	$N_{160}P_0K_0S_0Zn_0Fe_0$	211	211	43.84	42.58	221	218	8.60	8.35
T_3	$N_0P_{20}K_0S_0Zn_0Fe_0$	207	206	45.28	46.19	221	218	8.57	8.31
T_4	$N_{160}P_{20}K_0S_0Zn_0Fe_0$	225	226	49.46	50.92	231	229	8.65	8.38
T_5	$N_{160}P_{20}K_{60}S_0Zn_0Fe_0$	227	229	49.64	50.92	241	244	8.67	8.41
T_6	$N_{160}P_{20}K_0S_{20}Zn_0Fe_0$	225	226	50.37	51.47	234	234	9.88	10.02
T_7	$N_{160}P_{20}K_0S_0Zn_5Fe_0$	225	228	50.19	51.47	233	232	8.68	8.42
T_8	$N_{160}P_{20}K_0S_0Zn_0Fe_{10}$	225	229	49.64	51.11	235	234	8.71	8.50
T_9	$N_{160}P_{20}K_{60}S_{20}Zn_0Fe_0$	232	236	51.11	52.58	246	248	10.14	10.24
T_{10}	$N_{160}P_{20}K_{60}S_0Zn_5Fe_0$	227	234	49.46	50.92	245	247	8.73	7.72
T_{11}	$N_{160}P_{20}K_{60}S_0Zn_0Fe_{10}$	227	232	50.74	52.02	244	246	8.75	8.49
T_{12}	$N_{160}P_{20}K_{60}S_{20}Zn_5Fe_0$	239	244	51.84	53.13	250	250	10.10	10.17
T_{13}	$N_{160}P_{20}K_{60}S_{20}Zn_0Fe_{10}$	238	238	51.66	53.13	247	249	10.32	10.43
T_{14}	$N_{160}P_{20}K_{60}S_{20}Zn_5Fe_{10}$	239	245	51.84	53.50	252	254	10.59	10.70
T	S. Em±	6	6	0.87	1.19	6	5	0.28	0.24
	C. D. at 5 %	16	19	2.53	3.47	17	16	0.81	0.69
C.V.%		4.31	4.86	3.06	4.12	4.34	3.93	5.23	4.55

Table 4. Effect of nutrient omission on available Zn, Fe, Mn and Cu after harvest of maize

Treatment No.	Treatments	Available Zn (mg kg^{-1})		Available Fe (mg kg^{-1})		Available Mn (mg kg^{-1})		Available Cu (mg kg^{-1})	
		2022	2023	2022	2023	2022	2023	2022	2023
T_1	Control	0.77	0.73	5.99	5.96	11.10	11.85	1.30	1.53
T_2	$N_{160}P_0K_0S_0Zn_0Fe_0$	0.82	0.80	6.08	5.87	11.71	12.09	1.39	1.39
T_3	$N_0P_{20}K_0S_0Zn_0Fe_0$	0.81	0.80	6.00	5.85	11.18	12.21	1.41	1.37
T_4	$N_{160}P_{20}K_0S_0Zn_0Fe_0$	0.88	0.83	6.10	5.98	11.64	12.13	1.48	1.48
T_5	$N_{160}P_{20}K_{60}S_0Zn_0Fe_0$	0.87	0.87	6.32	6.09	12.48	12.40	1.50	1.47
T_6	$N_{160}P_{20}K_0S_{20}Zn_0Fe_0$	0.87	0.86	6.27	6.05	12.54	12.37	1.41	1.42
T_7	$N_{160}P_{20}K_0S_0Zn_5Fe_0$	0.89	0.93	6.25	6.04	12.57	12.23	1.46	1.46
T_8	$N_{160}P_{20}K_0S_0Zn_0Fe_{10}$	0.86	0.86	6.38	6.54	11.83	12.25	1.48	1.41
T_9	$N_{160}P_{20}K_{60}S_{20}Zn_0Fe_0$	0.88	0.87	6.35	6.07	12.42	12.21	1.41	1.46
T_{10}	$N_{160}P_{20}K_{60}S_0Zn_5Fe_0$	0.89	0.92	6.33	6.06	12.31	12.44	1.42	1.52
T_{11}	$N_{160}P_{20}K_{60}S_0Zn_0Fe_{10}$	0.87	0.87	6.42	6.60	12.72	12.47	1.52	1.51
T_{12}	$N_{160}P_{20}K_{60}S_{20}Zn_5Fe_0$	0.90	0.93	6.37	6.01	12.74	12.34	1.55	1.44
T_{13}	$N_{160}P_{20}K_{60}S_{20}Zn_0Fe_{10}$	0.87	0.87	6.47	6.65	12.71	12.48	1.56	1.55
T_{14}	$N_{160}P_{20}K_{60}S_{20}Zn_5Fe_{10}$	0.90	0.94	6.50	6.68	12.76	12.52	1.59	1.41
S. Em±		0.03	0.02	0.22	0.20	0.43	0.34	0.05	0.04
C. D. at 5 %		NS	0.07	NS	0.58	NS	NS	NS	NS
C.V.%		5.80	4.68	6.21	5.60	6.07	4.86	6.43	5.18

4. CONCLUSION

According to the findings of a two-year experiment, higher available nitrogen, phosphorus, potassium and sulphur in soil after harvesting of maize was observed under the application of $N_{160}P_{20}K_{60}S_{20}Zn_5Fe_{10}$ kg ha^{-1} (T_{14}) treatment during both the year. Significantly lower available nitrogen, phosphorus, potassium and sulphur in soil observed with control during 2022 and 2023. Nutrient omission treatments did not significantly affect the available zinc and iron contents in the soil after maize harvest in 2022. However, in 2023, available zinc was significantly higher in treatment T_{14}. The lowest zinc and iron content observed in the control treatment (T_1). The omission plot technique is an effective method to identify the particular nutrient deficiency.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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