Study on Nano-Zn, Inorganic, and Organic Nutrient Management Practices and Their Impact on Nutrient Availability in Kharif Maize (*Zea mays* L.)

Abstract

To evaluate the effect of Nano-Zn, inorganic, and organic nutrient management practices on the physico-chemical properties and nutrient availability in kharif maize (*Zea mays* L.) grown during the years 2022 and 2023 at Chandra Shekhar Azad University of Agriculture & Technology, Kanpur. The experiment was laid out in a split-plot design, with organic manures (Control, FYM at 10 t/ha, and Vermicompost at 5 t/ha) as the main plot treatments, and different nutrient management practices (Control, 75% RDF, 75% RDF + $ZnSO_4$ at 25 kg/ha, 75% RDF + Nano-Zn at 10 ml/liter, 100% RDF, 100% RDF + $ZnSO_4$, and 100% RDF + Nano-Zn) as the subplot treatments. The results revealed that the use of 100% RDF combined with Nano-Zn and $ZnSO_4$ significantly improved soil nutrient availability and physico-chemical properties compared to control treatments. Organic carbon content was highest in the 100% RDF + Nano-Zn treatment (0.492%), indicating improved soil organic matter. Nitrogen availability was significantly higher in the same treatment, with a pooled value of 151.167 kg/ha, compared to 143.443 kg/ha in the control. Phosphorus levels were also elevated in the 100% RDF + Nano-Zn treatment (16.337 kg/ha), highlighting enhanced phosphorus mobilization. Potassium availability improved as well, with the highest value (216.39 kg/ha) recorded in the 100% RDF + Nano-Zn treatment, while the control had 213.597 kg/ha. Zinc availability was most notably affected, with the 100% RDF + Nano-Zn treatment exhibiting 0.853 mg/kg, substantially higher than the control at 0.79 mg/kg. The study demonstrated that the integration of Nano-Zn and $ZnSO_4$ with inorganic fertilizers led to improved soil fertility, nutrient availability, and potentially better crop performance in kharif maize. These findings suggest that the combined application of inorganic and nano-fertilizers could be an effective strategy for enhancing nutrient management and promoting sustainable agricultural practices in maize cultivation, ultimately leading to improved productivity and soil health.

Keywords: *Nano-Zn, Organic manures, Nutrient management, Soil fertility, Nutrient availability*

Introduction

Maize (*Zea mays* L.), a globally significant cereal crop, holds a prominent place in the agricultural economy due to its versatile use as food, feed, and industrial raw material. In India, it is cultivated during both kharif and rabi seasons, with kharif maize contributing significantly to the total maize production [1]. However, achieving optimum productivity is often constrained by nutrient deficiencies, particularly in regions with poor soil fertility. Nutrient management, therefore, plays a pivotal role in sustaining crop growth, enhancing yield, and improving nutrient availability in the soil. Maize is cultivated on a global scale, covering approximately 207.25 million hectares across 160 countries, yielding 1,217.30 million tonnes of production with an average yield of 5.87 metric tonnes per hectare (USDA, 2021-22). In India, maize ranks as the third most important cereal crop after rice and wheat, grown on 10.10 million hectares with a production of 33.60 million tonnes and an average yield of 3.33 metric

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tonnes per hectare [2]. In Uttar Pradesh alone, maize is cultivated on 0.73 million hectares, producing 1.53 million tonnes with a productivity rate of 2,095.8 kg per hectare [3].

In recent years, increasing attention has been given to the use of nano-fertilizers as a sustainable and efficient alternative to conventional fertilizers. Nano-Zinc (Nano-Zn) has emerged as a key innovation in this regard, offering potential advantages over traditional zinc fertilizers due to its enhanced reactivity, slow release, and ability to improve nutrient uptake by plants. Zinc, being an essential micronutrient, is critical for various physiological processes in plants, including enzyme activation, protein synthesis, and growth regulation. Zinc deficiency is a common problem in maize cultivation, particularly in zinc-deficient soils, affecting both crop yield and nutrient content [4]. The integration of nano-fertilizers with traditional inorganic and organic nutrient management practices presents an innovative approach to address nutrient deficiencies and improve the overall nutrient use efficiency in crops. Inorganic fertilizers, though widely used, often result in nutrient losses due to leaching and volatilization, which not only affects crop productivity but also causes environmental degradation. On the other hand, organic nutrient sources such as composts and manures improve soil health by enhancing microbial activity, increasing organic matter content, and improving nutrient availability over time. The combination of these nutrient management strategies nano-Zn, inorganic, and organic fertilizers offers a synergistic potential to improve nutrient availability and sustain soil fertility. This study aims to investigate the impact of Nano-Zn, inorganic, and organic nutrient management practices on the availability of nutrients in kharif maize. By examining the interaction of these different nutrient sources, the research seeks to explore how they influence the nutrient dynamics in the soil, plant growth, and overall crop productivity.

Material and Methods

The experiment was conducted during the years 2022 and 2023 at the Students' Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture & Technology, Kanpur. The study employed a split-plot design, with organic manures assigned to the main plots and different nutrient management practices to the sub-plots. The geographic location of the experimental site is between 25°26' to 26°58' North latitude and 79°31' to 31°34' East longitude, at an elevation of 125.9 meters above sea level in the alluvial Indo-Gangetic Plain zone of central Uttar Pradesh. Sand content was 24.86% (2022) and 24.88% (2023), silt was 53.94% and 53.97%, and clay was 21.20% and 21.19%, classifying the soil as silt loam. Particle density was 2.56 Mg/m^3 (2022) and 2.55 Mg/m^3 (2023), while bulk density was 1.37 Mg/m^3 and 1.36 Mg/m^3. Soil pH was 7.72 (2022) and 7.67 (2023), with organic carbon content of 0.43% and 0.44%. Electrical conductivity measured 5.4 dSm^{-1} (2022) and 5.3 dSm^{-1} (2023). Available nitrogen was 135.40 kg/ha and 138.25 kg/ha, phosphorus (P_2O_5) was 13.50 kg/ha and 14.28 kg/ha, potassium (K_2O) was 210.45 kg/ha and 214.25 kg/ha, and zinc was 77.01 g/ha and 78.32 g/ha. The region experiences a sub-tropical climate with an annual rainfall of approximately 890 mm, predominantly received from mid-June to September. The crop growing seasons witnessed cold, dry winters, with occasional frost and variable meteorological conditions recorded during both years, including mean weekly maximum and minimum temperatures ranging from 29.3°C to 37.7°C and 16.0°C to 28.5°C in 2022, and 31.4°C to 35.6°C and 14.5°C to 28.9°C in 2023. The main plot treatments involved three organic manure applications: control (O1), FYM at 10 t/ha (O2), and vermicompost at 5 t/ha (O3). In the sub-

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plots, seven different nutrient management treatments were evaluated: control (M1), 75% RDF (120:60:60 NPK kg/ha) (M2), 75% RDF + $ZnSO_4$ at 25 kg/ha (M3), 75% RDF + Nano-Zinc at 10 ml/liter (M4), 100% RDF (M5), 100% RDF + $ZnSO_4$ at 25 kg/ha (M6), and 100% RDF + Nano-Zinc at 10 ml/liter (M7). The maize variety used for this study was DKC (DEKALB)-9144, a full maturity hybrid produced by Bayer Crop Science Ltd., which is well-suited for both rainfed and irrigated conditions, with a yield potential of 74-86 q/ha and a maturity period of 105-115 days.

The methods for estimating soil properties were based on standard scientific procedures. Bulk density was determined using the core method as described by [5]. Particle density was estimated following the pycnometer method outlined by [6]. Soil pH was measured using a pH meter in a 1:2.5 soil-water suspension, according to the procedure by [7]. Electrical conductivity (EC) was determined using an EC meter in a 1:2 soil-water extract following the method of [8]. Cation exchange capacity (CEC) was estimated using the ammonium acetate extraction method as described by [9]. Organic carbon (OC) was estimated using the wet oxidation method by [10]. Available nitrogen (N) was determined by the alkaline permanganate method as described by [11]. Available phosphorus (P) was measured using the Olsen method, developed by [12]. Available potassium (K) was determined by the flame photometer method following [13]. Available zinc (Zn) was estimated using the diethylene triamine pentaacetic acid (DTPA) extraction method by [14].

Result and Discussion

The study on Nano-Zn, inorganic, and organic nutrient management practices on the physico-chemical properties of kharif maize during 2022 and 2023 demonstrated (Table 1) minimal variations across treatments in bulk density, particle density, soil pH, electrical conductivity, and cation exchange capacity (CEC). Bulk density ranged from 1.370 Mg/m^3 in the 100% RDF treatment to 1.380 Mg/m^3 in the control treatment, with no significant differences observed between treatments or years. Particle density varied slightly, with values ranging from 2.547 Mg/m^3 in the control treatment to 2.607 Mg/m^3 in the 100% RDF + Nano-Zn treatment, though these differences were also not statistically significant. Soil pH remained relatively stable across treatments, with values ranging from 7.467 in the 100% RDF + ZnSO4 treatment to 7.671 in the control, indicating that nutrient management practices did not significantly affect soil pH, which remained slightly alkaline. Electrical conductivity (EC) showed no significant changes, with values between 5.573 dSm^{-1} in the control and 5.587 dSm^{-1} in the 100% RDF + Nano-Zn treatment, reflecting stable salinity levels. The CEC values, however, showed some improvement with the 100% RDF + Nano-Zn treatment, which had the highest CEC value of 48.157 cmol/kg, compared to the control treatment's 44.307 cmol/kg, indicating a slightly enhanced nutrient-holding capacity in treatments involving Nano-Zn and $ZnSO_4$. Despite these minor improvements in CEC, the overall impact of different nutrient management practices on the physico-chemical properties of the soil was minimal across both years **[15], [16], [17].**

The study on Nano-Zn, inorganic, and organic nutrient management practices in kharif maize revealed that treatments (Table 2) involving 100% RDF combined with Nano-Zn and ZnSO4 significantly improved the availability of key nutrients such as nitrogen (N), phosphorus (P), potassium (K), and zinc (Zn) in the soil. Organic carbon (OC) content was highest in the 100% RDF + Nano-Zn treatment (0.492%), indicating enhanced organic matter. Similarly, nitrogen availability was highest in the same treatment, with a pooled value of 151.167 kg/ha, compared

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to 143.443 kg/ha in the control, showing that the combination of inorganic and Nano-Zn fertilizers enhanced nitrogen levels in the soil. Phosphorus availability also followed this pattern, with the 100% RDF + Nano-Zn treatment recording the highest phosphorus levels (16.337 kg/ha), while the control was significantly lower. Potassium availability was also elevated in the RDF treatments, with 216.39 kg/ha in the 100% RDF + Nano-Zn treatment compared to 213.597 kg/ha in the control. Zinc availability showed the most significant increase in the treatments involving $ZnSO_4$ and Nano-Zn, with the 100% RDF + Nano-Zn treatment yielding 0.853 mg/kg, significantly higher than the control at 0.79 mg/kg. These results indicate that the application of Nano-Zn and $ZnSO_4$ in combination with full doses of inorganic fertilizers substantially improves soil nutrient availability, enhancing soil fertility and supporting better crop growth and yield in kharif maize **[18], [19], [20].**

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Table: 1 Studies of Nano- Zn, inorganic and organic nutrient management practices on Available Physico-chemical properties of *kharif* Maize

Treatments	Available Bulk Density			Available Particle Density			Available Ph			Available EC			Available CEC		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Organic Manures (Main plot)															
Control	1.379	1.379	1.379	2.566	2.570	2.568	7.671	7.643	7.657	5.580	5.577	5.579	45.051	45.081	45.066
FYM -10 t/ha	1.376	1.377	1.376	2.583	2.587	2.585	7.586	7.529	7.557	5.579	5.579	5.579	46.584	46.717	46.651
Vermi Compost- 5 t/ha	1.370	1.373	1.371	2.589	2.590	2.589	7.629	7.529	7.579	5.577	5.580	5.579	46.946	47.169	47.057
SE(d) ±	**0.011**	**0.012**	**0.011**	**0.022**	**0.022**	**0.022**	**0.063**	**0.062**	**0.062**	**0.046**	**0.046**	**0.046**	**0.402**	**0.406**	**0.403**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**1.147**	**1.159**	**1.149**
Nutrient Management (Sub plot)															
Control	1.38	1.38	1.38	2.547	2.55	2.548	7.7	7.633	7.667	5.573	5.573	5.573	44.307	44.34	44.323
75 % RDF (@120:60:60 NPK kg/ha)	1.377	1.383	1.38	2.57	2.573	2.572	7.6	7.6	7.6	5.573	5.573	5.573	45.107	45.04	45.073
75 % RDF + $ZnSO_4$ (@ 25 kg/ha)	1.377	1.377	1.377	2.577	2.577	2.577	7.7	7.6	7.65	5.577	5.58	5.578	45.643	45.88	45.762
75 % RDF + Nano- Zinc - (@ 10 ml/litre)	1.373	1.377	1.375	2.583	2.58	2.582	7.633	7.567	7.6	5.583	5.577	5.58	46.383	46.517	46.45
100 % RDF (@120:60:60 NPK kg/ha)	1.37	1.37	1.37	2.583	2.59	2.587	7.633	7.6	7.617	5.58	5.577	5.578	46.893	46.977	46.935
100 % RDF + $ZnSO_4$ (@ 25 kg/ha)	1.373	1.373	1.373	2.597	2.6	2.598	7.567	7.467	7.517	5.583	5.583	5.583	47.347	47.347	47.347
100 % RDF + Nano- Zinc -	1.373	1.373	1. 373	2.597	2.607	2.602	7.567	7.5	7.533	5.58	5.587	5.583	47.677	48.157	47.917

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(@ 10 ml/litre)															
SE(d) ±	**0.011**	**0.041**	**0.041**	**0.077**	**0.077**	**0.077**	**0.226**	**0.225**	**0.226**	**0.166**	**0.166**	**0.166**	**1.377**	**1.381**	**1.379**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Interaction (A x B)															
SE(d) ±	**0.067**	**0.067**	**0.067**	**0.125**	**0.125**	**0.125**	**0.368**	**0.366**	**0.367**	**0.270**	**0.270**	**0.270**	**2.245**	**2.252**	**2.248**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Interaction (B x A)															
SE(d) ±	**0.071**	**0.071**	**0.071**	**0.133**	**0.133**	**0.133**	**0.392**	**0.389**	**0.391**	**0.287**	**0.287**	**0.287**	**2.386**	**2.392**	**2.389**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table: 2 Studies of Nano- Zn, inorganic and organic nutrient management practices on Available Nutrient in *kharif* Maize

Treatment	**Available OC (%)**			**Available N (Kg/ha)**			**Available P (Kg/ha)**			**Available K (Kg/ha)**			**Available Zn (mg/kg)**		
	2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
Organic Manures (Main plot)															
Control	0.471	0.471	0.471	147.254	144.521	145.888	15.474	15.477	15.476	213.467	214.749	214.108	0.796	0.809	0.802
FYM -10 t/ha	0.481	0.489	0.485	148.933	148.571	148.752	15.953	15.903	15.928	215.104	215.921	215.513	0.827	0.837	0.832
Vermi Compost- 5 t/ha	0.487	0.494	0.491	149.780	149.403	149.591	16.029	16.174	16.101	215.310	216.190	215.750	0.834	0.844	0.839
SE(d) ±	**0.004**	**0.004**	**0.004**	**1.258**	**1.286**	**1.272**	**0.140**	**0.140**	**0.140**	**1.801**	**1.802**	**1.796**	**0.007**	**0.007**	**0.007**
CD (P=0.05)	**0.012**	**0.012**	**0.012**	**NS**	**3.667**	**NS**	**0.395**	**0.400**	**0.398**	**NS**	**NS**	**NS**	**0.020**	**0.021**	**0.021**
Nutrient Management (Sub plot)															
Control	0.47	0.47	0.47	145.85	141.037	143.443	15.193	15.197	15.195	212.927	214.267	213.597	0.78	0.8	0.79

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75 % RDF (@120:60:60 NPK kg/ha)	0.48	0.48	0.48	147.52	145.12	146.32	15.637	15.643	15.64	213.827	214.493	214.16	0.8	0.81	0.805
75 % RDF + $ZnSO_4$ (@ 25 kg/ha)	0.477	0.483	0.48	148.46	146.727	147.593	15.763	15.657	15.71	214.577	215.597	215.087	0.813	0.827	0.82
75 % RDF + Nano- Zinc - (@ 10 ml/litre)	0.477	0.48	0.478	148.947	147.673	148.31	15.787	15.71	15.748	214.67	215.633	215.152	0.82	0.827	0.823
100 % RDF (@120:60:60 NPK kg/ha)	0.483	0.49	0.487	149.133	149.333	149.233	15.99	15.993	15.992	215.06	215.723	215.392	0.833	0.833	0.833
100 % RDF + $ZnSO_4$ (@ 25 kg/ha)	0.487	0.493	0.49	150.177	150.77	150.473	16.157	16.29	16.223	215.647	216.53	216.088	0.84	0.853	0.847
100 % RDF + Nano- Zinc - (@ 10 ml/litre)	0.487	0.497	0.492	150.503	151.83	151.167	16.203	16.47	16.337	215.683	217.097	216.39	0.847	0.86	0.853
SE(d) ±	**0.014**	**0.014**	**0.014**	**4.422**	**4.396**	**4.409**	**0.472**	**0.472**	**0.472**	**6.383**	**6.409**	**6.396**	**0.024**	**0.025**	**0.025**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Interaction (B x A)															
SE(d) ±	**0.023**	**0.024**	**0.023**	**7.202**	**7.165**	**7.183**	**0.769**	**0.769**	**0.769**	**10.393**	**10.434**	**10.413**	**0.040**	**0.040**	**0.040**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Interaction (A x B)															
SE(d) ±	**0.025**	**0.025**	**0.025**	**7.659**	**7.613**	**7.636**	**0.817**	**0.817**	**0.817**	**11.056**	**11.101**	**11.079**	**0.042**	**0.043**	**0.043**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

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Conclusion

The study concluded that the application of 100% RDF combined with Nano-Zn and $ZnSO_4$ significantly enhanced the availability of essential nutrients such as nitrogen, phosphorus, potassium, and zinc in the soil. These treatments resulted in higher organic carbon content, improved nitrogen levels, better phosphorus mobilization, increased potassium availability, and substantial zinc enrichment compared to control treatments. The combination of inorganic fertilizers with Nano-Zn and $ZnSO_4$ proved to be an effective strategy for improving soil fertility, leading to better nutrient uptake and potentially higher crop yields in kharif maize. Thus, integrating Nano-Zn and $ZnSO_4$ with traditional nutrient management practices offers a promising approach for sustainable agriculture and enhanced crop productivity.

References

1. Kumari, M., Meena, L. K., & Singh, R. G. (2015). Problems and prospects of maize crop in eastern zone of Bihar. International Journal of Agricultural Science and Research, 5(2), 137-146.
2. USDA, (2021-22). World agriculture supply and demand estimate.
3. DAC & FW (2018-19). Agricultural Statistics Division. Estimates of Production of Food grains for 2018-19. Directorate of Economics and Statistics; Department of Agriculture, Cooperation and Farmers Welfare; Ministry of Agriculture and Farmers Welfare, Government of India.
4. Suganya, A., Saravanan, A., & Manivannan, N. (2020). Role of zinc nutrition for increasing zinc availability, uptake, yield, and quality of maize (Zea mays L.) grains: An overview. Commun. Soil Sci. Plant Anal, 51(15), 2001-2021.
5. Blake, G. R. (1986). Bulk density. Methods of Soil Analysis. Part, 1.
6. Flint, L. E., & Flint, A. L. (2002). 2.3 Porosity. Methods of soil analysis: part 4 physical methods, 5, 241-254.
7. Jackson, R. D. (1973). Diurnal changes in soil water content during drying. Field soil water regime, 5, 37-55.
8. Richards, L. A. (Ed.). (1954). Diagnosis and improvement of saline and alkali soils (No. 60). US Government Printing Office.
9. Chapman, C. H. (1976). Exact and approximate generalized ray theory in vertically inhomogeneous media. Geophysical Journal International, 46(2), 201-233.
10. Subbiah, S. and Asija, J. 1956. A rapid producer for the estimation of available nitrogen in soil, Current Sci. 25: 259-260.
11. Olsen, S. R. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate (No. 939). US Department of Agriculture.
12. Hanway, J.J. and Heidel, H. (1952) Soil analysis methods as used in Iowa State College, Soil Testing Laboratory, Iowa State College Bulletin 57, 1-131.
13. Lindsay, W. L., & Norvell, W. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil science society of America journal, 42(3), 421-428.
14. Apoorva, M. R., Rao, P. C., & Padmaja, G. (2017). Effect of zinc with special reference to nano zinc carrier on yield, nutrient content and uptake by rice (Oryza sativa L.). Int J Curr Microbiol App Sci, 6(8), 1057-1063.

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15. Chandrashekara, C. P. (2021). Soil and plant nutrient status of cotton as influenced by different methods of application of nano ZnO. Journal of pharmacognosy and phytochemistry, 10(2), 1386-1389.
16. Jangid, B., Srinivas, A., Kumar, M. R., Ramprakash, T., Prasad, T. N. V. K. V., Kumar, A. K., ... & Dida, V. K. (2019). Influence of zinc oxide nanoparticles foliar application on zinc uptake of rice (Oryza sativa L.) under different establishment methods. International Journal of Chemical Studies, 7(1), 257-261.
17. Borase, C. L., Lomte, D. M., Thorat, S. D., & Dhonde, A. S. (2018). Response of Kharif maize (Zea mays L.) to micronutrients. Journal of Pharmacognosy and Phytochemistry, 7(3), 482-484.
18. Kumar, K., Bhaskar, M. K., & Sahu, B. K. (2020). Response of kharif maize on growth parameters and protein yield under different lateral arrangement and nutrient levels using drip irrigation. Journal of Pharmacognosy and Phytochemistry, 9(3), 1037-1040.
19. Hussain, M. Z., Kumar, M., Singh, R., Kumari, S., Mandal, D., Kumar, R. R., & Manohar, T. P. B. (2019). Effect of different levels of potassium on nutrient content and uptake by Kharif maize (Zea mays L.). International Journal of Chemical Studies, 7(6), 2118-2122.
20. Mylavarapu, R., Sikora, F. J., & Moore, K. P. (2014). Walkley-Black Method. *Soil test methods from the Southeastern United States*, *158*.

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