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Effect of Nitrogen, Copper and Zinc Liquid Nano Fertilizers on Soil Properties, Nutrient Concentration, Uptake and Nutrient Use Efficiency of Potato (*Solanum tuberosum* L.)

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Abstract

A field experiment was conducted in farmer's field at Madenur village of Hassan district during *rabi* 2020, to study the 'Effect of nano-nitrogen, copper and zinc liquid fertilizers on nutrient concentration, uptake and efficiency in potato (*Solanum tuberosum* L.)'. The experiment was laid out in randomized complete block design comprising ten treatments replicated thrice. The treatment includes combined and individual application of nano fertilizers *i.e.* nitrogen, copper and zinc liquid fertilizers at 0.4 per cent to see the release of the nutrients, uptake and its efficiency compared with a conventional fertilizer. The results revealed that significantly higher nitrogen, copper and zinc concentration in potato haulm and tuber, uptake and efficiency of applied nutrients was observed in treatment T_{10} which received 50 per cent N, 50 per cent Zn and 100 per cent PK application to soil inorganically along with 1st spray of Nano N at 25-30 DAP + 2nd spray of nano Zn after 10-15 days of 1st spray + 3rd spray of nano Cu after 10-15 days of 2nd spray, although the release of N, Zn and Cu was higher for applied nano fertilizer than the conventional one. Analysis showed higher accumulation of N, Zn and Cu in plants applied with nano fertilizer. Post-effect of nano fertilizer concentration and uptake increased in plant with nano fertilizer treatment than the conventional fertilizer.

Keywords : Nano fertilizers, Foliar spray, Micronutrients, Potato haulm

The potato (*Solanum tuberosum* L.) is a starchy tuber and a root vegetable native to the Americas. The plant is a perennial in the night shade family Solanaceae. Potato (*Solanum tuberosum* L.) is widely used for many industrial and food applications and considered one of the most important vegetable crops in India and it is most economically valuable vegetable crop, after tomato (Birch *et al*., 2012). The vegetative and fruiting parts of the potato contain the toxin solanine which is dangerous for human consumption. Normal potato tubers that have been grown and stored properly produce glyco alkaloids in amounts small enough to be negligible to human health but if green sections of the plant are exposed to light, the tuber can accumulate a high enough concentration of glycoalkaloids to affect human health.

Modern agriculture depends mostly on inorganic fertilizers, a greater portion of which is readily removed from soil after harvesting. Nowadays growers are striving to overcome the nutrient deficiency and approach the genetic limit of plants. Resorting to replace these nutrients is the ultimate choice. Because of agricultural development, different parts of the world have evidenced that fertilizer application is the most efficient measure for increasing crop production, sustainable yield growth and food security. Fertilization increases crop yields at a rate of 30 to 50 per cent, globally. About

40 - 70 per cent of the nitrogen and 80 - 90 per cent of the phosphorus of the applied fertilizers either are lost into the environment or become unavailable for crops. It not only causes major economic and resource loss but also is responsible for serious environmental pollution.

To overcome the problem of fertilizer use and increase economical use, number of approaches have been made. Among them: application of adequate amount of fertilizer; deep placement of fertilizer; use of granular urea; improving crop response knowledge and use of slow release nano fertilizer are notable (Ahmed *et al*. 2012).

Nano fertilizer, the most important field of agriculture, has drawn the attention of the soil scientists as well as the environmentalists due to its capability to increase yield, improve soil fertility, reduce pollution and make a favourable environment for microorganisms. Nano particles with small size and large surface area are expected to be the ideal forms for use as a fertilizer in plants. Farmers are applying different fertilizers for soil and as foliar applications; however, the efficacy is low (Uma *et al*., 2019). So that, application of nano fertilizers in minute quantity improves crop growth and reduces environmental pollution (Pruthviraj *et al*., 2022). According to the present study, the rate of release of nutrients from laboratory synthesized nano fertilizer and its effects on crop production have been compared with ordinary chemical fertilizer.

Material and Methods

The experiment was conducted during *rabi* 2020 to study effect of nitrogen, copper and zinc liquid nano fertilizers on soil properties, nutrient concentration, uptake and nutrient use efficiency of potato (*Solanum tuberosum* L.) at farmers field Madenur, College of Agriculture, Hassan, Karnataka. Experiment was laid out in a randomised complete block design with ten treatments and three replicates. Treatments of this research comprised of three nano fertilizers (Nano nitrogen, nano copper and nano zinc at 0.4 per cent concentration) under field conditions, potato crop uptake and use efficiency of nano fertilizers were studied.

Treatments Involved

T_1 - Control (0% N and Zn, 100% P & K fertilizers)

T_2 - Control + 2 sprays of water,

T_3 - Control + 2 sprays of Nano Nitrogen @ 0.4%

T_4 - Control + 2 sprays of Nano Zinc @ 0.4%

T_5 - Control + 2 sprays of Nano Copper @ 0.4%

T_6 - RDF (100% NPK and $ZnSO_4$ @ 6 kg ha^{-1}); 125:100:125 NPK kg ha^{-1} soil application

T_7 - RDF (50% N 100% PK) soil application + 2 sprays of Nano Nitrogen

T_8 - RDF (50% Zn 100% NPK) soil application + 2 sprays of Nano Zinc

T_9 - RDF + 2 sprays of Nano Copper

T_{10} - RDF (50% N, 50% Zn & 100% PK) + 1st spray of Nano N at 25-30 DAP + 2nd spray of nano Zn after 10-15 days of 1st spray + 3rd spray of nano Cu after 10-15 days of 2nd spray.

Where, RDF was recommended dose of fertilizers (125:100:125 NPK kg ha^{-1}) and 100 per cent P and K is common for all treatment.

Collection of Soil and Plant Samples

The initial soil samples were collected from different sites of experimental field and a composite sample was prepared. The initial soil sample was analysed for various chemical properties. Treatment wise soil samples were collected after harvest and were air dried, the clods were gently broken using wooden mallet, sieved through 2 mm sieve and stored in polythene bags for further analysis. The initial soil samples before treatment imposition was collected and subjected for analysis physico-chemical properties such as soil texture, pH and EC by Jackson (1973), OC (Walkley and Black, 1934), DTPA extractable available micro (Lindsay and Norvell, 1978) and macro nutrients.

The nutrient composition of the plant species is not a fixed entity. It varies from time to time in plants, soil to soil and even species to species. Hence, a specific plant part should be selected at a definite stage of the plant growth. The physiologically matured plant part should be selected as it will not undergo rapid changes in nutrient composition. The haulms were collected at 75 days after planting and the tubers were collected after harvest. The collected samples were first air dried, then oven dried at 65 ^{0}C for 48 hours, grounded in a Wiley mill and stored in brown paper covers for chemical analysis. Representative plant samples were collected treatment wise and analysed for total NPK nutrients in haulm and tuber. The uptake of these nutrients by potato crop was computed and the results were expressed in kg ha^{-1} on dry weight basis by using below formula.

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Percentage of nutrients x Total dry matter production (kg/ha)}}{100}$$

Nutrient Use Efficiency (NUE) is a critically important concept in the evaluation of crop production systems. NUE was calculated by using partial factor productivity (Dua *et al.*, 2007).

$$\text{Partial factor productivity (kg/kg)} = \frac{\text{Total yield (kg / ha)}}{\text{Amount of nutrient applied (kg / ha)}}$$

Results and Discussion

Soil Characteristics of the Experimental Site

Some common physicochemical properties of the soil were analysed before the experimental setup in order to know the initial nutrient status of the soil and represented in Table 1. The experimental soil was silty loam in texture, slightly acidic in reaction (pH 6.13). The soil having organic carbon 0.82 per cent, electrical conductivity 0.23 dS m^{-1}, available Nitrogen 274.45 kg ha^{-1}, available Phosphorous 27.30 kg ha^{-1}, available potassium 156.50 kg ha^{-1}, Exchangeable Ca and Mg 2.95 and 1.18 cmol kg^{-1}, respectively, Available Sulphur 10.21 mg kg^{-1}, DTPA Extractable Fe, Zn, Mn and Cu 37.53, 0.95, 10.31 and 0.32 mg kg^{-1} respectively, Hot water-soluble Boron 0.25 mg kg^{-1} .

Table 1

Soil initial properties

Soil properties	Values obtained
pH (1:2.5) soil water suspension	6.13
EC (dS m^{-1}) soil water extract	0.23
Organic carbon (%)	0.82
Available N (kg ha^{-1})	274.45
Available P_2O_5 (kg ha^{-1})	27.30
Available K_2O (kg ha^{-1})	156.50
Exchangeable Ca and Mg (cmol kg^{-1})	2.95 & 1.18
Available S (mg kg^{-1})	10.21
DTPA Extractable Fe, Zn, Mn and Cu (mg kg^{-1})	37.53, 0.95, 10.31 & 0.32 respectively
Hot water-soluble Boron (mg kg^{-1})	0.25

Soil Chemical Properties and Nutrient Status after the Harvest of Potato Crop

Initial Soil Chemical Properties : The data on effect of nano nitrogen, copper and zinc liquid fertilizers on potato is presented in Table 1. The soil parameters like pH, EC, Soil organic carbon and organic matter of soil did not show any significant difference. However, the higher pH, EC and OC (6.22, 0.44 dSm^{-1} and 0.83 %, respectively) was found in the treatment T_{10}. Here it is observed that there is a slight increase in pH, EC and OC compare to initial values, it may be due to basal application of fertilizers, FYM and crop residues. Elumalai and Velmurugan in 2015, recorded similar observations in red soils of Tamil Nadu, they also reported that higher buffering capacity of soils will resist the minute change in pH and EC.

Post-Harvest Nutrient Status of the Soil : The nutrient status *viz.*, available N, P_2O_5, K_2O, S, exchangeable Ca and Mg, DTPA extractable Zn, Cu, Mn, Fe and B of the soil after harvest of potato are presented in Table 2.

Among the macro nutrients the available nitrogen content of the soil after harvest of potato crop was found significant over the control but with respect to available phosphorus and potassium content of the soil after harvest of potato crop did not show any significant difference between the treatments imposed. It might be due to uniform application of phosphorous and potassium fertilizers with same amount of fertilizer to all the treatments. The presence of nitrogen in the available form leads to early growth, improves the quality of the yield and increases protein content. promotes absorption of other nutrients including potassium and phosphorus and promotes

TABLE 2

Effect of nano nitrogen, copper and zinc liquid fertilizers on soil chemical properties and nutrient status of the soil after the harvest of potato crop

Treat-ments	pH	EC (dSm^{-1})	OC (%)	N	P_2O_5	K_2O	Ca	Mg	S	Fe	Mn	Zn	Cu	B
				($kg\ ha^{-1}$)			($cmol\ (p^+)\ kg^{-1}$)			($mg\ kg^{-1}$)				
T_1	6.20	0.38	0.79	272.42	28.02	162.68	1.27	2.80	8.41	39.33	13.92	0.91	0.53	0.41
T_2	6.21	0.37	0.81	272.52	29.55	164.85	1.43	3.17	10.73	45.47	14.03	0.92	0.57	0.43
T_3	6.20	0.41	0.84	277.34	29.43	163.63	1.35	3.09	13.64	41.30	15.16	0.91	0.55	0.42
T_4	6.18	0.36	0.83	276.53	30.45	163.08	1.42	3.30	12.33	41.67	15.12	0.93	0.54	0.44
T_5	6.20	0.36	0.80	277.22	29.73	165.83	1.41	3.18	11.37	45.57	14.97	0.93	0.58	0.42
T_6	6.21	0.39	0.89	305.73	31.35	169.46	1.37	3.51	13.74	44.77	14.81	1.16	0.57	0.40
T_7	6.22	0.43	0.81	287.26	31.64	171.88	1.38	3.23	12.3	41.13	14.18	1.15	0.56	0.42
T_8	6.19	0.42	0.82	283.80	33.51	174.97	1.44	3.23	13.97	43.37	14.26	1.08	0.58	0.40
T_9	6.18	0.36	0.79	294.47	34.41	172.28	1.36	3.17	14.23	46.50	15.36	1.13	0.57	0.43
T_{10}	6.22	0.44	0.83	290.15	35.39	176.55	1.43	3.29	13.58	46.90	15.46	1.10	0.59	0.45
S. Em ±	0.04	0.02	0.02	13.35	3.03	34.52	0.047	0.115	1.190	2.02	0.71	0.07	0.02	0.01
CD @ 5%	NS	NS	NS	26.15	NS	NS	NS	NS	NS	NS	NS	0.20	NS	NS

Note:

T_1 : Control (0% N and Zn, 100% P and K fertilizers);
T_2 : Control + 2 sprays of water;
T_3 : Control + 2 sprays of Nano Nitrogen @ 0.4 %;
T_4 : Control + 2 sprays of Nano Zinc @ 0.4%;
T_5 : Control + 2 sprays of Nano Copper @ 0.4%;
T_6 : RDF (100% NPK and $ZnSO_4$ @ 6 kg ha^{-1}); 125:100:125 NPK kg ha^{-1};
T_7 : RDF (50% N 100% PK) + 2 sprays of Nano Nitrogen;
T_8 : RDF (50% Zn 100% NPK) + 2 sprays of Nano Zinc;
T_9 : RDF + 2 sprays of Nano Copper;
T_{10} : RDF (50% N, 50% Zn and 100% PK) + 1st spray of Nano N at 25-30 DAP + 2nd spray of nano Zn after 10-15 days of 1st spray + 3rd spray of nano Cu after 10-15 days of 2nd spray

total plant growth (Hemerly, 2016). Potassium has a catalytic effect in the main step of protein synthesis. The production of proteins and enzymes that regulate all growth processes, *i.e.* K deficiency in the plant, may affect the synthesis of proteins despite the availability of nitrogen (N). In respect of available nitrogen treatment T_6 worst significantly superior over T_1, T_2, T_3, T_4,T_5 and at par with T_7, T_8, T_9 and T_{10}.

With respect to secondary nutrients, there was no significant difference among different treatments with respect to Ca, Mg and S content in haulm and tuber of potato. It may be due to potato plants requires higher secondary nutrients throughout its growth and development and applied fertilizers supplies some proportion of all these nutrients in addition to the nano fertilizers, hence there was an increased secondary nutrient contents in the leaves over control though not significant. The present study is in compliance with the findings of Halemani *et al.* (2004).

Crop did not show any significant difference between treatments imposed with respect to micronutrients Cu, Fe, Mn and B content except Zn in soil after harvest of potato crop due to different treatments imposed. Among the micro nutrients, higher DTPA extractable zinc content was found in T_6 (1.10 mg kg^{-1}) followed by and T_7 (1.15 mg kg^{-1}) lowest DTPA extractable zinc content (0.91 mg kg^{-1}) of soil was found in both T_1 and T_3.

Increase in zinc is due to application of zinc sulphate fertilizers as a basal dose, the application of nano fertilizers to soil increased the soil available Zn and Fe as compared to control, Similar results were reported by Bala *et al*., (2019) and they also reported a significant increase in soil Zn content on foliar application of ZnO-NPs. Different concentrations of ZnO-NPs and days after treatments significantly affected other micro-nutrients also, *i.e*., Cu, Fe and Mn.

Effect on Nutrients Content (%) and Uptake (kg ha^{-1}) by Potato

The content and uptake of macro and micro nutrients in potato haulm and tuber at harvest are presented in Tables 3, 4, 5, 6 and 7.

Nutrient Content (%)

The nitrogen content in potato haulm and tuber differed significantly due to different treatments imposed (Table 3). Significantly higher nitrogen content in haulm and tuber (1.30 % and 1.34 %, respectively) was recorded in $T_{10,}$ followed by T_7 (1.26 % and 1.28). Among all the treatments, lowest N content in haulm and tuber (1.13 % and 1.07 %, respectively) was recorded in (T_1) Control. These results are in harmony with those found by Kisan *et al.* (2015) who studied the effect of nano-zinc on the leaf physical and nutritional status of spinach in nitrogen and phosphorous content of leaves. Manikandan and Subramanian (2015) also reported that highest N content was registered in roots of maize plants fertilized with nanozeourea (0.32 %).

The zinc content in potato haulm and tuber differed significantly due to different treatments imposed (Table 5). Significantly highest zinc content in haulm and tuber (73.45 and 15.64 mg kg^{-1}, respectively) was recorded in T_8. It was found significant over all the treatments except T_{10} (73.01 and 14.22 mg kg^{-1}, respectively), these treatments found on par with each other in haulm and tuber zinc content. Significantly higher copper content in haulm and tuber of potato (46.91 and 26.34 mg kg^{-1}, respectively) was recorded in T_9 which received RDF + 2 sprays of Nano Copper. It was found significant over all the treatments including control (25.61 mg kg^{-1}) except T_{10} (44.64 mg kg^{-1}) and T_5 (44.39 mg kg^{-1}) in copper content of haulm. However, these treatments were found on par with each other in copper content in haulm. Whereas, in tuber it was significant over control (17.15 mg kg^{-1}). Among the all treated plots lower copper content in both haulm and tuber (25.61 and 17.15 mg kg^{-1}, respectively) was found in (T_1) Control 0 per cent N and Zn, 100 per cent P and K fertilizers, which was found on par with T_2 (18.26 mg kg^{-1}) in tuber copper content. The role of Cu in flower formation is thought to be related to its activation of polyphenol and Indole Acetic Acid (IAA) oxidases, enzymes involved in the oxidation of IAA (Bhakuni *et al.,* 2009).

TABLE 3

Effect of nano nitrogen, copper and zinc liquid fertilizers on nutrient content of N, P_2O_5, K_2O, Ca, Mg and S (%) in haulm and tuber of potato after harvest.

Treat-ments	Nitrogen (%)		Phosphorous (%)		Potassium (%)		Calcium (%)		Magnesium (%)		Sulphur (%)	
	Haulm	Tuber	Haulm	Tuber	Haulm	Tuber	Haulm	Tuber	Haulm	Tuber	Haulm	Tuber
T_1	1.13	1.07	0.21	0.23	1.71	1.34	0.95	0.23	0.97	0.21	0.23	0.40
T_2	1.15	1.19	0.23	0.25	1.94	1.45	1.06	0.25	1.06	0.23	0.26	0.41
T_3	1.26	1.23	0.25	0.29	2.05	1.53	1.18	0.32	1.12	0.26	0.29	0.48
T_4	1.17	1.25	0.23	0.25	1.88	1.50	1.09	0.30	1.05	0.25	0.28	0.47
T_5	1.21	1.22	0.24	0.26	1.96	1.41	1.10	0.29	1.1	0.23	0.28	0.51
T_6	1.23	1.24	0.25	0.29	2.12	1.53	1.13	0.29	1.14	0.25	0.29	0.49
T_7	1.26	1.28	0.24	0.26	1.97	1.48	1.20	0.31	1.10	0.25	0.30	0.50
T_8	1.19	1.25	0.22	0.25	2.18	1.44	1.17	0.30	1.14	0.27	0.31	0.50
T_9	1.16	1.24	0.24	0.27	2.17	1.45	1.16	0.28	1.11	0.26	0.30	0.49
T_{10}	1.30	1.34	0.25	0.31	2.2	1.58	1.23	0.34	1.21	0.30	0.32	0.53
S. Em. ±	0.030	0.025	0.013	0.015	0.113	0.044	0.06	0.02	0.04	0.02	0.02	0.03
CD @ 5%	0.09	0.07	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Note:

T_1 : Control (0% N and Zn, 100% P and K fertilizers);
T_2 : Control + 2 sprays of water;
T_3 : Control + 2 sprays of Nano Nitrogen @ 0.4 %;
T_4 : Control + 2 sprays of Nano Zinc @ 0.4%;
T_5 : Control + 2 sprays of Nano Copper @ 0.4%;
T_6 : RDF (100% NPK and $ZnSO_4$ @ 6 kg ha^{-1}); 125:100:125 NPK kg ha^{-1};
T_7 : RDF (50% N 100% PK) + 2 sprays of Nano Nitrogen;
T_8 : RDF (50% Zn 100% NPK) + 2 sprays of Nano Zinc;
T_9 : RDF + 2 sprays of Nano Copper;
T_{10} : RDF (50% N, 50% Zn and 100% PK) + 1st spray of Nano N at 25-30 DAP + 2nd spray of nano Zn after 10-15 days of 1st spray + 3rd spray of nano Cu after 10-15 days of 2nd spray

TABLE 4

Effect of nano nitrogen, copper and zinc liquid fertilizers on nutrient uptake of N, P_2O_5, K_2O, Ca, Mg and S (kg ha^{-1}) in haulm and tuber of potato after harvest

Treat-ments	Nitrogen (kg ha^{-1})			Phosphorous (kg ha^{-1})			Potassium (kg ha^{-1})			Calcium (kg ha^{-1})			Magnesium (kg ha^{-1})			Sulphur (kg ha^{-1})		
	H	T	To	H	T	To	H	T	To	H	T	To	H	T	To	H	T	To
T_1	9.87	25.32	35.20	1.98	5.48	7.46	14.87	31.83	46.71	8.25	5.54	13.79	8.45	4.91	13.36	1.98	9.40	11.37
T_2	10.06	27.74	37.80	1.99	5.93	7.92	17.12	33.82	50.94	9.31	5.77	15.08	9.28	5.38	14.66	2.25	9.51	11.76
T_3	15.65	34.36	50.01	3.14	7.63	10.76	25.39	41.12	66.51	14.03	7.80	21.83	13.66	6.70	20.37	3.55	12.85	16.40
T_4	14.25	31.12	45.37	2.55	6.30	8.85	22.87	37.40	60.27	13.32	7.38	20.70	12.75	6.23	18.98	3.40	11.71	15.11
T_5	13.89	29.72	43.61	2.76	6.26	9.02	22.53	34.14	56.67	12.68	7.10	19.78	12.62	5.50	18.12	3.17	12.31	15.49
T_6	15.29	34.70	49.99	3.10	8.04	11.14	26.32	42.79	69.11	14.91	8.52	23.44	14.17	7.02	21.19	3.60	13.83	17.43
T_7	17.02	46.03	63.04	3.18	10.70	13.88	25.77	54.42	80.19	16.10	11.68	27.78	15.75	10.33	26.08	3.92	17.29	21.20
T_8	15.19	39.38	54.57	2.85	7.77	10.62	28.09	45.32	73.41	14.94	9.78	24.72	14.58	8.64	23.23	3.95	15.74	19.69
T_9	14.77	38.26	53.03	3.17	8.22	11.40	27.51	44.61	72.12	14.77	8.62	23.40	14.09	8.03	22.12	3.85	15.21	19.06
T_{10}	18.54	43.48	62.01	3.47	9.35	12.83	32.05	52.47	84.52	17.31	11.24	28.55	16.39	9.31	25.69	4.69	18.80	23.49
S. Em ±	0.34	1.41	3.09	0.17	0.56	0.69	1.38	2.18	4.11	0.68	0.68	1.61	0.48	0.51	1.41	0.22	0.83	1.30
CD @ 5%	1.00	4.20	9.17	0.50	1.68	2.06	4.11	6.49	12.20	2.02	2.02	4.78	1.41	1.52	4.20	0.64	2.45	3.86

H-haulm, T-tuber, To-total uptake

Note :

T_1 : Control (0% N and Zn, 100% P and K fertilizers);
T_2 : Control + 2 sprays of water;
T_3 : Control + 2 sprays of Nano Nitrogen @ 0.4 %;
T_4 : Control + 2 sprays of Nano Zinc @ 0.4%;
T_5 : Control + 2 sprays of Nano Copper @ 0.4%;
T_6 : RDF (100% NPK and $ZnSO_4$ @ 6 kg ha^{-1}); 125:100:125 NPK kg ha^{-1};
T_7 : RDF (50% N 100% PK) + 2 sprays of Nano Nitrogen;
T_8 : RDF (50% Zn 100% NPK) + 2 sprays of Nano Zinc;
T_9 : RDF + 2 sprays of Nano Copper;
T_{10} : RDF (50% N, 50% Zn and 100% PK) + 1st spray of Nano N at 25-30 DAP + 2nd spray of nano Zn after 10-15 days of 1st spray + 3rd spray of nano Cu after 10-15 days of 2nd spray

TABLE 5

Effect of Nano nitrogen, copper and zinc liquid fertilizers on Fe, Mn, Zn, Cu and B content (mg kg^{-1}) in potato

Treat-ments	Iron		Manganese		Zinc		Copper		Boron	
	Haulm	Tuber	Haulm	Tuber	Haulm	Tuber	Haulm	Tuber	Haulm	Tuber
T_1	203.03	133.16	179.91	34.68	32.07	10.75	25.61	17.15	9.42	21.47
T_2	234.22	149.43	204.6	39.40	38.34	11.62	35.07	18.26	10.42	25.56
T_3	235.15	155.37	224.93	46.47	53.18	13.04	37.72	21.04	10.85	29.87
T_4	247.86	152.77	217.93	39.08	68.17	13.75	40.43	20.30	10.57	29.15
T_5	253.56	153.10	210.23	38.24	55.56	12.83	44.39	22.81	11.25	29.07
T_6	248.40	155.40	223.30	46.30	56.75	12.82	41.90	21.71	11.49	30.61
T_7	245.90	155.82	236.73	46.19	67.38	13.54	42.92	22.54	11.21	30.77
T_8	253.63	153.70	210.10	46.10	72.01	14.22	39.62	20.18	10.61	30.00
T_9	251.21	155.43	215.46	45.73	53.55	13.35	44.64	23.03	10.85	29.13
T_{10}	250.00	161.90	243.36	47.31	73.45	15.64	46.91	26.34	11.54	31.22
S. Em ±	10.20	4.82	11.30	3.08	2.86	0.46	1.51	0.75	0.40	1.92
CD @ 5%	NS	NS	NS	NS	8.48	1.36	4.48	2.23	NS	NS

Note:

T_1 : Control (0% N and Zn, 100% P and K fertilizers);
T_2 : Control + 2 sprays of water;
T_3 : Control + 2 sprays of Nano Nitrogen @ 0.4 %;
T_4 : Control + 2 sprays of Nano Zinc @ 0.4%;
T_5 : Control + 2 sprays of Nano Copper @ 0.4%;
T_6 : RDF (100% NPK and $ZnSO_4$ @ 6 kg ha^{-1}); 125:100:125 NPK kg ha^{-1};
T_7 : RDF (50% N 100% PK) + 2 sprays of Nano Nitrogen;
T_8 : RDF (50% Zn 100% NPK) + 2 sprays of Nano Zinc;
T_9 : RDF + 2 sprays of Nano Copper;
T_{10} : RDF (50% N, 50% Zn and 100% PK) + 1st spray of Nano N at 25-30 DAP + 2nd spray of nano Zn after 10-15 days of 1st spray + 3rd spray of nano Cu after 10-15 days of 2nd spray

Nutrient Uptake (kg ha^{-1})

The total uptake of nitrogen by potato crop differed significantly due to different treatments imposed (Table 4). Significantly highest nitrogen uptake (63.04 kg ha^{-1}) was recorded in T_7, over all other treatments including control (35.20 kg ha^{-1}) but except T_{10} (62.01 kg ha^{-1}) and T-$_8$ (54.57 kg ha^{-1}). However, these treatments found on par with each other. Among the all treatments imposed, lower uptake (35.20 kg ha^{-1}) was found in (T_1) Control. When a nanoengineered composite which consists of N, P, K, micronutrients, mannose and amino acids was applied to grain crops, it appeared to enhance the uptake and use of nutrients (Abdel-Aziz *et al.*, 2018). Mohamad Yatim *et al.* (2016) also reported that N fertilizer uptake was recorded for UF-MWCNT's treatment which recorded which was higher than that of control.

The total uptake of zinc content by potato differed significantly due to different treatments imposed (Table 6). Significantly the higher zinc uptake was recorded in T_{10} (161.21 g ha^{-1}) over all other treatments including control (53.56 g ha^{-1}) except T_7 (134.67 g ha^{-1}) and T_8 (138.66 g ha^{-1}). However, these treatments found on par with each other and lower total uptake of Zn (53.56 g ha^{-1}) was found in T_1 with Control 0 per cent N and Zn, 100 per cent P and K fertilizers, which was found non significant over T_2 (60.84 g ha^{-1}). Zinc is the precursor of IAA, due to these enzymes in oxidation of IAA and increased the concentration and uptake of zinc and in most of studies indicated that Nitrogen addition results in significant increases in the availabilities of micronutrients, such as the available concentrations of Cu, Mn and Fe in soils (Wang *et al*. 2017).

The total uptake of copper by potato haulm and tuber was found significant by the application of

TABLE 6

Effect of Nano nitrogen, copper and zinc liquid fertilizers on Fe, Mn and Zn uptake (g ha^{-1}) by potato

Treat-ments	Iron (g ha^{-1})			Manganese (g ha^{-1})			Zinc (g ha^{-1})		
	Haulm	Tuber	Total	Haulm	Tuber	Total	Haulm	Tuber	Total
T_1	176.88	316.95	493.84	156.75	82.38	239.13	27.94	25.62	53.56
T_2	205.64	349.46	555.11	179.11	92.00	271.11	33.69	27.15	60.84
T_3	291.19	417.93	709.12	278.55	125.14	403.69	65.84	35.08	100.93
T_4	301.01	379.82	680.82	264.62	97.10	361.72	82.79	34.08	116.87
T_5	291.24	372.47	663.71	241.37	92.38	333.75	63.72	31.12	94.85
T_6	307.86	436.39	744.25	276.74	129.59	406.32	70.38	35.95	106.33
T_7	326.42	557.32	883.74	317.73	162.99	480.72	87.97	46.70	134.67
T_8	324.14	484.71	808.85	268.27	145.78	414.05	93.85	44.81	138.66
T_9	319.00	479.77	798.78	273.64	141.12	414.77	67.99	41.19	109.18
T_{10}	361.09	552.47	913.55	347.45	163.73	511.18	105.67	55.54	161.21
S. Em ±	14.38	22.73	44.70	12.79	9.71	28.33	3.51	1.83	11.10
CD @ 5%	42.72	67.54	132.81	37.99	28.86	84.18	10.44	5.45	32.97

Note:

T_1 : Control (0% N and Zn, 100% P and K fertilizers);
T_2 : Control + 2 sprays of water;
T_3 : Control + 2 sprays of Nano Nitrogen @ 0.4 %;
T_4 : Control + 2 sprays of Nano Zinc @ 0.4%;
T_5 : Control + 2 sprays of Nano Copper @ 0.4%;
T_6 : RDF (100% NPK and $ZnSO_4$ @ 6 kg ha^{-1}); 125:100:125 NPK kg ha^{-1};
T_7 : RDF (50% N 100% PK) + 2 sprays of Nano Nitrogen;
T_8 : RDF (50% Zn 100% NPK) + 2 sprays of Nano Zinc;
T_9 : RDF + 2 sprays of Nano Copper;
T_{10} : RDF (50% N, 50% Zn and 100% PK) + 1st spray of Nano N at 25-30 DAP + 2nd spray of nano Zn after 10-15 days of 1st spray + 3rd spray of nano Cu after 10-15 days of 2nd spray

nano nitrogen, copper and zinc liquid fertilizers on potato crop (Table 7). Significantly higher copper uptake was recorded in T_{10} (161.43 g ha^{-1}) and it is superior over all other treatments including control (63.11 g ha^{-1}). Among all the treatments imposed the lower total uptake of Copper (63.11 g ha^{-1}) was found in T_1 which received 0 per cent N and Zn, 100 per cent P and K fertilizers, which was found on par with T_2 with (73.47 g ha^{-1}) in copper uptake by potato crop. Higher uptake might be due to nano fertilizers are excellent alternatives for soluble conventional chemical fertilizers where the nutrients are released at slower rates throughout the growth cycle and uptake of nutrients before leaching (Sohair *et al.,* 2018 and Eissa, 2019).

Nutrient Use Efficiency (NUE)

The data obtained on nutrient use efficiency of nitrogen, phosphorous and potassium was presented in terms of partial factor productivity in the Table 8. The higher nutrient use efficiency of nitrogen, phosphorous and potassium was recorded in the treatment T_{10} (462, 289 and 231 kg kg^{-1}, respectively). Nano fertilizer have large surface area and particle size less than the pore size of root and leaves of the plant which can increase penetration into the plant from applied surface and improve uptake and nutrient use efficiency of the nano fertilizer. Reduction of particle size results in increased specific surface area and number of particles per unit area of a fertilizer that provide more opportunity to contact of nano-fertilizers which leads to more penetration and uptake of the nutrient. Fertilizers encapsulated in nano-particles will increase availability and uptake of nutrient to the crop plants (Tarafdar *et al*., 2012).

Based on the experiment conducted and results obtained it is concluded that, combined application of nano nitrogen, copper and zinc liquid fertilizers

TABLE 7

Effect of Nano nitrogen, copper and zinc liquid fertilizers on Cu and B uptake (g ha^{-1}) by potato

Treatments	Copper (g ha^{-1})			Boron (g ha^{-1})		
	Haulm	Tuber	Total	Haulm	Tuber	Total
T_1	22.32	40.79	63.11	8.21	51.16	59.37
T_2	30.77	42.70	73.47	9.15	59.81	68.96
T_3	46.70	56.60	103.30	13.44	80.57	94.01
T_4	49.09	50.47	99.56	12.84	72.48	85.32
T_5	50.95	55.49	106.43	12.92	70.68	83.60
T_6	51.93	60.93	112.85	14.31	87.69	102.00
T_7	56.04	77.82	133.86	15.00	105.83	120.84
T_8	50.66	63.59	114.25	13.54	94.73	108.27
T_9	59.56	71.12	130.68	13.77	89.99	103.76
T_{10}	67.72	93.71	161.43	16.45	108.51	124.96
S. Em ±	1.91	3.78	9.54	0.46	6.56	7.06
CD @ 5%	5.67	11.23	28.34	1.37	19.50	20.98

Note :

T_1 : Control (0% N and Zn, 100% P and K fertilizers);
T_2 : Control + 2 sprays of water;
T_3 : Control + 2 sprays of Nano Nitrogen @ 0.4 %;
T_4 : Control + 2 sprays of Nano Zinc @ 0.4%;
T_5 : Control + 2 sprays of Nano Copper @ 0.4%;
T_6 : RDF (100% NPK and $ZnSO_4$ @ 6 kg ha^{-1}); 125:100:125 NPK kg ha^{-1};
T_7 : RDF (50% N 100% PK) + 2 sprays of Nano Nitrogen;
T_8 : RDF (50% Zn 100% NPK) + 2 sprays of Nano Zinc;
T_9 : RDF + 2 sprays of Nano Copper;
T_{10} : RDF (50% N, 50% Zn and 100% PK) + 1st spray of Nano N at 25-30 DAP + 2nd spray of nano Zn after 10-15 days of 1st spray + 3rd spray of nano Cu after 10-15 days of 2nd spray

TABLE 8

Effect of Nano nitrogen, copper and zinc liquid fertilizers on nutrient use efficiency of N, P_2O_5 and K_2O (kg kg^{-1}) by potato

Treatments	Yield (kg ha^{-1})	Nutrient applied (kg ha^{-1})			Nutrient use efficiency (kg kg^{-1})		
		N	P_2O_5	K_2O	N use efficiency	P_2O_5 use efficiency	K_2O use efficiency
T_1	18614	0	100	125	0	186	149
T_2	18805	0	100	125	0	188	150
T_3	23069	0	100	125	0	231	185
T_4	22619	0	100	125	0	226	181
T_5	20336	0	100	125	0	203	163
T_6	25625	125	100	125	205	256	205
T_7	27697	62.82	100	125	441	277	222
T_8	26847	125	100	125	215	268	215
T_9	26553	125	100	125	212	266	212
T_{10}	28931	62.66	100	125	462	289	231

Note :

T_1 : Control (0% N and Zn, 100% P and K fertilizers);
T_2 : Control + 2 sprays of water;
T_3 : Control + 2 sprays of Nano Nitrogen @ 0.4 %;
T_4 : Control + 2 sprays of Nano Zinc @ 0.4%;
T_5 : Control + 2 sprays of Nano Copper @ 0.4%;
T_6 : RDF (100% NPK and $ZnSO_4$ @ 6 kg ha^{-1}); 125:100:125 NPK kg ha^{-1};
T_7 : RDF (50% N 100% PK) + 2 sprays of Nano Nitrogen;
T_8 : RDF (50% Zn 100% NPK) + 2 sprays of Nano Zinc;
T_9 : RDF + 2 sprays of Nano Copper;
T_{10}: RDF (50% N, 50% Zn and 100% PK) + 1st spray of Nano N at 25-30 DAP + 2nd spray of nano Zn after 10-15 days of 1st spray + 3rd spray of nano Cu after 10-15 days of 2nd spray.

shows increased nutrient content and efficiency of potato crop and also improved the uptake of that particular nutrient. But these nano fertilizers did not influence the soil chemical and nutrient status. Buffering capacity of soil resists the small changes in the chemical properties and application of nano fertilizers in lesser quantity did not show any significant difference on soil chemical properties and nutrient status of soil. Application of nano fertilizers in a very small quantity improves crop growth and reduces environmental pollution. It is also concluded that nano fertilizers in general, and Nano-N in particular, will successfully help in reducing the consumption of urea to 50 per cent by applying 2 sprays of Nano-N. Other products *viz.,* Nano-Zinc and Nano-Copper would show their effectiveness depending upon the magnitude of deficiencies of these nutrients in soils.

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