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Impact of foliar application of different nano-fertilizers on soil microbial properties and yield of wheat

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Abstract

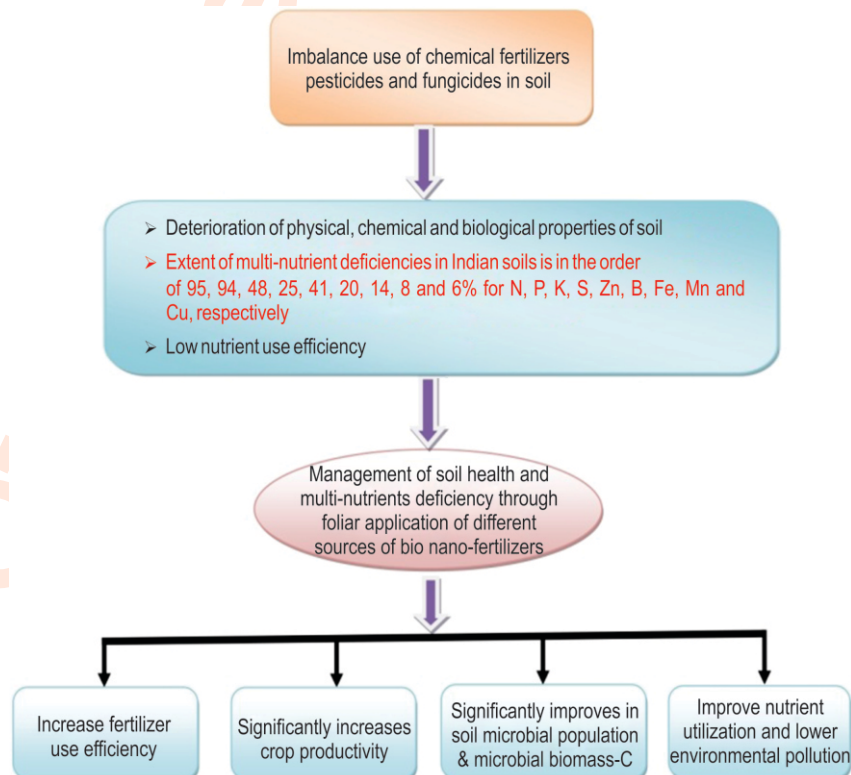
Aim: The present investigation was carried out to study the effect of foliar application nano-fertilizers P, K and Zn on yield, nutrient content and uptake by wheat and soil microbial properties in sub-humid southern plains of Rajasthan.

Methodology: The experiment was laid out in triplicate following randomized block design with fifteen treatments comprising foliar application of different doses of Nano P, K and Zn.

Results: Foliar application of 1st spray of Nano Zn at 14 days after sowing (DAS) + 2nd spray of Nano Zn at 28 DAS along with 100% recommended dose of fertilizers (RDF) significantly ($P=0.05$) increased yield attributes and nutrient uptake in wheat. The significantly ($P=0.05$) maximum microbial population (bacteria and fungi) and microbial biomass-C was obtained with 1st spray of Nano P at 14 DAS + 2nd spray of Nano P at 28 DAS along with 100% recommended dose of fertilizers (RDF).

Interpretation: Foliar application of nano fertilizers led to significant improvement of crop productivity of wheat in sub-humid southern plain of Rajasthan. Moreover, the foliar application of nano-fertilizers, i.e., Nano P also stimulated microbial growth by providing nutrients and directly increased their population in soil.

Key words: Biomass-C, Foliar application, Nano-fertilizers, Soil microbial population, Wheat productivity



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Introduction

Wheat (*Triticum aestivum* L.) is the second most important food grain cereal crop next to rice in India contributing about 35% of the food grain production covering an area of 29.58 million hectares with annual production of 99.70 million tonnes with a productivity of 3371 kg ha⁻¹ during 2017-18 (Tiwari et al., 2019). Wheat has significantly contributed towards the success of green revolution and has greatly helped to transform our country from a situation of hand to mouth to being self-sufficient. The increase in crop productivity mainly depends on the fertilizers used to supplement essential nutrients to crop plants. The importance of micronutrients, i.e., Zn in small amount exerts a positive effect on photosynthesis and thus, improves yield and quality (Hänsch and Mendel, 2009). Macronutrients like N, P, and K in sufficient quantity throughout the growing season is essential for optimum growth (Haque et al., 2001). Phosphorus, as a constituent of ADP and ATP, plays a key role in energy transformation and storage. It also helps in the assimilation of photosynthates into other metabolites and, hence, acts as an activity zone for CO₂ assimilation.

Potassium is an essential nutrient and also the most abundant cation in plants. It plays an essential role in enzyme activation, protein synthesis, photosynthesis, osmoregulation, stomatal movement, energy transfer, phloem transport, cation-anion balance and stress resistance (Gul et al., 2015). Likewise, zinc is an essential element for the activities of a number of antioxidant enzymes which maintains the membrane lipids, proteins and nucleic acids in plant cells (Cakmak, 2008). Nano-fertilizers deal with the elements in nanometer dimensions (1–100 nm) and at nanoscale, these fertilizers release the nutrients at a slower rate for a longer period, consequently, limiting nutrient loss from the soil and reducing soil-groundwater pollution (Meena et al., 2017). Nano-fertilizers have an important role in the physiological and biochemical processes of crops by increasing the availability of nutrients, which help in enhancing metabolic processes and promoting meristematic activities causing higher apical growth and photosynthetic area (DeRosa et al., 2010). Nanoparticles have unique physico-chemical properties and key potential to boost the plant metabolism (Zulfiqar et al., 2019; Raliya et al., 2018).

The efficiency of nanoparticles is determined by their chemical composition, size, surface covering, reactivity and most important the dose at which they are effective (Jyothi and Hebsur, 2017; Shang et al., 2019). Nano-fertilizers have better nutrient use efficiency due to their better penetration ability and translocation within plant parts (Ghorbanpour et al., 2017; Kopittke et al., 2019), moreover, they prevent undesirable loss of nutrient via direct internalization by crops, and thereby, avoid the interaction of nutrients with soil, water, air and microorganisms (Panpattee et al., 2016). Nanofertilizers also have controlled release and targeted delivery of effective nanoscale ingredients/nutrients and have the ability to improve plant productivity and minimize environmental pollutants (Fatima et al., 2020). Nanofertilizers promote plant

growth and crop production by supplying essential nutrients in nano form with high fertilizers use efficiency, ultrahigh absorption due to small size, minimizing potential negative effects associated with over dosage, reducing the frequency of application of fertilizers, low cost due to decline cost of environment protection, maintain soil fertility and soil health thus, it is a new emerging cost effective and eco-friendly alternative to conventional fertilizers. It offers generous visions for sustainable agriculture crop production through improvement of quality food production with minimizing its negative impact on human health as well as environment (Sekhon, 2014). Because of the shortage of arable land, limited water and nutrient resources, the development of agriculture sector is only possible by increasing resource use efficiency with minimum damage to production bed through effective use of modern technologies (Naderi and Shahraki, 2013). The use of nano-fertilizers instead of conventional synthetic fertilizers is a way to release nutrient into soil in controlled and conditional way thus, reducing the loss of nutrients, soil toxicity in soil and maintain sustainability and protection of agriculturally produced food (Arif et al., 2016).

Foliar application is a technique of feeding plants by spraying liquid fertilizers directly to the leaves, which is accompanied with better absorption in the aerial parts (Nasiri et al., 2010; Marzouk et al., 2019). The efficacy of foliar fertilization is higher than that of soil fertilizer application under drought and salinity condition due to supply of required nutrient directly to the leaves, its relatively quick absorption, independence of root activity and soil water availability (Romheld and El-Fouly, 1999). Foliar nano zinc, copper and iron fertilizers application on grain crops increases growth parameters of wheat relative to other fertilizer sources (Ghorbanpour et al., 2017). Hence, looking to the above facts, the present investigation was carried out to study the impact of foliar application of nano-fertilizers on soil microbial population, biomass-C and productivity of wheat in the sub-humid southern plains of Rajasthan.

Materials and Methods

Study area: The experiment was conducted during rabi 2018-19 at the Instructional Farm, Rajasthan College of Agriculture, Udaipur. The region falls under agro-climatic zone-IVA (Sub-humid Southern Plains and Aravalli Hills) of Rajasthan. The climate of the study area is sub-humid with an average minimum and maximum temperature (October-April) ranging between 8.81 to 37.29°C during winter season.

Soil analyses: Post-harvest soil samples (0-15 cm depth) collected from each plot after crop harvest were air-dried, ground to pass through a 2 mm sieve using a wooden pestle and mortar and analyzed for microbial biomass-C by chloroform fumigation-extraction method (Vance et al., 1987). Serial dilution plating method (Vance et al., 1987) was used to enumerate viable counts for soil microbial populations (bacteria and fungi). Plates with serial dilution plating were incubated for 5 days and the number of colonies on different dilution media plates was recorded and the population per gram soil was enumerated.

Experimental design and treatments: The experiment was laid out in a randomized block design and replicated thrice in the plot size of 2.25 m x 3.0 m (6.75 m²). The experiment consisted of 15 treatments viz., T1: Control; T2: 100% RDF; T3: 100% RDF+ 1st spray of water at 14 DAS; T4: 100% RDF+ 1st spray of Nano P at 14 DAS; T5: 100% RDF+ 1st spray of Nano K at 14 DAS; T6: 100% RDF+ 1st spray of Nano Zn at 14 DAS; T7: 100% RDF+ 1st spray of Nano P at 14 DAS + 2nd spray of Nano P at 28 DAS; T8: 100% RDF+ 1st spray of Nano K at 14 DAS + 2nd spray of Nano K at 28 DAS; T9: 100% RDF+ 1st spray of Nano Zn at 14 DAS + 2nd spray of Nano Zn at 28 DAS; T10: 75% RDF+ 1st spray of Nano P at 14 DAS + 2nd spray of Nano P at 28 DAS; T11: 75% RDF+ 1st spray of Nano K at 14 DAS + 2nd spray of Nano K at 28 DAS; T12: 75% RDF+ 1st spray of Nano Zn at 14 DAS + 2nd spray of Nano Zn at 28 DAS; T13: 50% RDF+ 1st spray of Nano P at 14 DAS + 2nd spray of Nano P at 28 DAS; T14: 50% RDF+ 1st spray of Nano K at 14 DAS + 2nd spray of Nano K at 28 DAS and T15: 50% RDF+ 1st spray of Nano Zn at 14 DAS + 2nd spray of Nano Zn at 28 DAS were applied to wheat var. Raj-3077 in rabi session, 2019-20. The recommended dose of fertilizer were 90 kg N, 60 kg P₂O₅, 35 kg K₂O and 25 kg ZnSO₄ ha⁻¹ and also other agronomic practices recommended for Zone IV-A were followed as per Package of Practices, Government of Rajasthan. The grains obtained from the produce of individual plot were recorded as grain yield kg per plot and later it was converted into kg ha⁻¹.

Application protocol of foliar spray: Foliar sprays were given as 1st application at 14 days after sowing and 2nd application at 28 days after sowing in selected treatments with the help of knapsack sprayer with flat fan nozzle. Nano P and K were applied @ 80 ml l⁻¹ water while Nano Zn @ 20 ml l⁻¹ water as per scheduled treatments.

Estimation of yield attributes: The number of effective tillers (ear bearing tillers), yield and yield attributing character were recorded as per standard methods (Singh *et al.*, 2018). The effective tillers (ear bearing tillers) were counted non-destructively from two randomly selected rows in each plot of each replicate and were averaged to number of effective tillers per meter row length in each plot. The grain and straw yield was recorded from the net plot area of each treatment.

Nutrient uptake: Plant samples of grain and straw of wheat collected at harvest were ground in Willey mill to pass through 40 mesh sieves. The samples were used for determination of phosphorus, potassium and zinc content in grain and straw by following standard procedure. The phosphorus content was determined by vanado-molybdo-phosphoric acid yellow colour method (Jackson, 1973) and K content was measured with a flame photometer (Johnson, 1959). The zinc content was determined by Atomic absorption spectrophotometrically suggested by Lindsay and Norvell (1978). Nutrient uptake in grain and straw was calculated by multiplying the nutrient concentration (%) in grain and straw by their respective yield.

Soil microbial properties: Soil samples (0-15 cm depth) were collected at harvest of the crop from each treatment plot for analysis. The samples were stored in plastic bags and taken to the laboratory, where the soil was sieved (2 mm mesh size), homogenized and stored at 4°C. The fungal, bacterial and actinomycetes population were estimated by standard plate count method using Marten's for fungi (Martin, 1950), and nutrient agar medium for bacteria and actinomycetes (Allen, 1959). Microbial population was calculated and expressed as number of cells per gram soil. The microbial biomass carbon (MBC) was measured by fumigation-extraction method and calculated by the following formula: Biomass C = EC/kEc where, kEc is 0.38 (Vance *et al.*, 1987).

Statistical analysis: All obtained data were subjected to statistically analysis of variance (ANOVA) as described by Panse and Sukhatme (1985). The critical difference was worked out at 5 per cent (0.05) probability levels.

Results and Discussion

Application of foliar spray of nano-fertilizer enhanced the number of effective tillers per meter row length, grain and straw yield of wheat significantly (Table 1). The maximum number of effective tillers per meter row length (80.16), grain yield (5565.20 kg ha⁻¹) and straw yield (7135.46 kg ha⁻¹) were observed under the treatment T9 (100% RDF + 1st spray of Nano Zn at 14 DAS + 2nd spray of Nano Zn at 28 DAS) followed by T12 (75% RDF+ 1st spray of Nano Zn at 14 DAS + 2nd spray of Nano Zn at 28 DAS), T10 (75% RDF+ 1st spray of Nano P at 14 DAS + 2nd spray of Nano P at 28 DAS), T11 (75% RDF+ 1st spray of Nano K at 14 DAS + 2nd spray of Nano K at 28 DAS) as compared to control. Nano fertilizers or nano-encapsulated nutrients have properties that are effective to crops, release the nutrients on-demand, controlled release of chemical fertilizers that regulate plant growth and enhanced target activity (Nair *et al.*, 2010).

Foliar application is a quick and effective treatment for plant nutrition, as it allows rapid uptake of nutrients during the fast-growing period of crop, especially soil deficient in available soil nutrients (Wojtkowiak *et al.*, 2014). It was evident from the present study that foliar application of Nano P, K and Zn manipulates growth parameters of wheat, resulting in significant improvement in yield and yield related components. The enhanced growth may be attributed to increased growth hormone and photosynthetic activities due to applications of nano-fertilizers. Moreover, the application of nano Zn enhances the metabolic processes of plants and photosynthesis, resulted increase flowering and grain formation, which ultimately increased the yield attributes. Several research findings have reported that nanofertilizers promote photosynthesis and plant growth (Wu, 2013; Fatima *et al.*, 2020). Nano-fertilizers viz., nano-NPK are considered as biological pumps of the plants to promote nutrients and water absorption in crop plants (Ma *et al.*, 2009). The results obtained in the present study collaborates with the previous reports where foliar spray of nano-fertilizers increased the yield and yield components of wheat crop (Zain *et*

Table 1: Effect of foliar application of nano-fertilizers on yield attributes and yield of wheat

Treatments		Number of effective tillers per meter row length	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)
T ₁ :	Control	55.13	3153.22	4048.18
T ₂ :	RDF	66.18	4007.81	5142.03
T ₃ :	100%RDF+ 1 st spray of water at 14 DAS	68.17	4260.16	5464.98
T ₄ :	100%RDF+ 1 st spray of Nano P at 14 DAS	71.10	4456.84	5716.73
T ₅ :	100%RDF+ 1 st spray of Nano K at 14 DAS	71.02	4405.25	5650.70
T ₆ :	100%RDF+ 1 st spray of Nano Zn at 14 DAS	72.01	4678.98	6001.09
T ₇ :	100%RDF+ 1 st spray of Nano P at 14 DAS + 2 nd spray of Nano P at 28 DAS	74.15	4987.21	6395.59
T ₈ :	100%RDF+ 1 st spray of Nano K at 14 DAS + 2 nd spray of Nano K at 28 DAS	74.01	4895.69	6278.54
T ₉ :	100%RDF+ 1 st spray of Nano Zn at 14 DAS + 2 nd spray of Nano Zn at 28 DAS	80.16	5565.20	7135.46
T ₁₀ :	75%RDF+ 1 st spray of Nano P at 14 DAS + 2 nd spray of Nano P at 28 DAS	77.01	5114.57	6557.26
T ₁₁ :	75%RDF+ 1 st spray of Nano K at 14 DAS + 2 nd spray of Nano K at 28 DAS	76.35	5100.97	6541.29
T ₁₂ :	75%RDF+ 1 st spray of Nano Zn at 14 DAS + 2 nd spray of Nano Zn at 28 DAS	79.47	5510.50	7066.37
T ₁₃ :	50%RDF+ 1 st spray of Nano P at 14 DAS + 2 nd spray of Nano P at 28 DAS	62.74	3757.34	4821.43
T ₁₄ :	50%RDF+ 1 st spray of Nano K at 14 DAS + 2 nd spray of Nano K at 28 DAS	61.36	3701.52	4749.93
T ₁₅ :	50%RDF+ 1 st spray of Nano Zn at 14 DAS + 2 nd spray of Nano Zn at 28 DAS	64.58	3898.23	5001.75
SEm±		2.13	131.66	170.84
CD(P=0.05)		6.16	381.42	494.91

100% RDF= Recommended dose of fertilizer- 90 kg N, 60 kg P₂O₅, 35 kg K₂O and 25 kg ZnSO₄ ha⁻¹; 75% RDF= Recommended dose of fertilizer- 67.5 kg N, 45 kg P₂O₅, 26.25 kg K₂O and 18.75 kg ZnSO₄ ha⁻¹ and 50% RDF= Recommended dose of fertilizer- 45 kg N, 30 kg P₂O₅, 17.50 kg K₂O and 12.5 kg ZnSO₄ ha⁻¹

Table 2: Effect of foliar application of nano-fertilizers on P, K and Zn uptake by grain and straw of wheat

Treatments	Phosphorus (kg ha ⁻¹)		Potassium (kg ha ⁻¹)		Zinc (g ha ⁻¹)		
	Grain	Straw	Grain	Straw	Grain	Straw	
T ₁ :	Control	8.35	6.68	14.75	53.48	145.00	121.95
T ₂ :	RDF	11.62	9.87	19.68	70.76	200.75	183.31
T ₃ :	100%RDF+ 1 st spray of water at 14 DAS	13.25	11.20	21.52	76.78	217.32	197.55
T ₄ :	100%RDF+ 1 st spray of Nano P at 14 DAS	14.71	12.29	22.68	80.66	232.06	212.72
T ₅ :	100%RDF+ 1 st spray of Nano K at 14 DAS	13.87	11.47	24.00	82.97	229.14	209.97
T ₆ :	100%RDF+ 1 st spray of Nano Zn at 14 DAS	14.65	12.05	23.73	84.41	271.74	245.81
T ₇ :	100%RDF+ 1 st spray of Nano P at 14 DAS + 2 nd spray of Nano P at 28 DAS	16.80	14.13	25.78	90.83	269.77	249.77
T ₈ :	100%RDF+ 1 st spray of Nano K at 14 DAS + 2 nd spray of Nano K at 28 DAS	15.59	13.26	27.13	93.55	265.51	244.91
T ₉ :	100%RDF+ 1 st spray of Nano Zn at 14 DAS + 2 nd spray of Nano Zn at 28 DAS	17.58	14.84	28.54	101.10	330.32	305.88
T ₁₀ :	75%RDF+ 1 st spray of Nano P at 14 DAS + 2 nd spray of Nano P at 28 DAS	17.17	14.35	26.01	92.15	275.66	252.83
T ₁₁ :	75%RDF+ 1 st spray of Nano K at 14 DAS + 2 nd spray of Nano K at 28 DAS	15.20	12.48	28.10	96.79	272.48	248.75
T ₁₂ :	75%RDF+ 1 st spray of Nano Zn at 14 DAS + 2 nd spray of Nano Zn at 28 DAS	16.26	13.43	27.72	99.00	324.28	298.56
T ₁₃ :	50%RDF+ 1 st spray of Nano P at 14 DAS + 2 nd spray of Nano P at 28 DAS	11.47	9.55	18.35	65.68	182.74	161.94
T ₁₄ :	50%RDF+ 1 st spray of Nano K at 14 DAS + 2 nd spray of Nano K at 28 DAS	10.55	8.69	19.51	68.94	178.53	156.80
T ₁₅ :	50%RDF+ 1 st spray of Nano Zn at 14 DAS + 2 nd spray of Nano Zn at 28 DAS	10.96	9.01	18.92	68.04	227.50	209.84
SEm±		0.615	0.389	0.942	3.05	13.54	9.69
CD(P=0.05)		1.78	1.12	2.72	8.83	39.22	28.09

100% RDF= Recommended dose of fertilizer- 90 kg N, 60 kg P₂O₅, 35 kg K₂O and 25 kg ZnSO₄ ha⁻¹; 75% RDF= Recommended dose of fertilizer- 67.5 kg N, 45 kg P₂O₅, 26.25 kg K₂O and 18.75 kg ZnSO₄ ha⁻¹ and 50% RDF= Recommended dose of fertilizer- 45 kg N, 30 kg P₂O₅, 17.50 kg K₂O and 12.5 kg ZnSO₄ ha⁻¹

Table 3: Effect of foliar application of nano-fertilizers on microbial population and biomass carbon in post harvest soil

Treatments	Microbial population		Microbial biomass-C (mg kg ⁻¹)
	Bacteria (X 10 ⁶)	Fungi (X 10 ⁴)	
T ₁ : Control	52.01	15.02	221.21
T ₂ : RDF	61.25	19.36	232.36
T ₃ : 100%RDF+ 1 st spray of water at 14 DAS	67.36	25.21	245.29
T ₄ : 100%RDF+ 1 st spray of Nano P at 14 DAS	71.65	28.54	249.01
T ₅ : 100%RDF+ 1 st spray of Nano K at 14 DAS	70.24	27.52	248.22
T ₆ : 100%RDF+ 1 st spray of Nano Zn at 14 DAS	69.11	26.85	247.54
T ₇ : 100%RDF+ 1 st spray of Nano P at 14 DAS + 2 nd spray of Nano P at 28 DAS	78.54	34.25	259.33
T ₈ : 100%RDF+ 1 st spray of Nano K at 14 DAS + 2 nd spray of Nano K at 28 DAS	77.21	33.42	257.14
T ₉ : 100%RDF+ 1 st spray of Nano Zn at 14 DAS + 2 nd spray of Nano Zn at 28 DAS	76.36	32.12	256.41
T ₁₀ : 75%RDF+ 1 st spray of Nano P at 14 DAS + 2 nd spray of Nano P at 28 DAS	76.51	31.41	254.25
T ₁₁ : 75%RDF+ 1 st spray of Nano K at 14 DAS + 2 nd spray of Nano K at 28 DAS	75.25	30.65	253.03
T ₁₂ : 75%RDF+ 1 st spray of Nano Zn at 14 DAS + 2 nd spray of Nano Zn at 28 DAS	74.26	29.54	252.21
T ₁₃ : 50%RDF+ 1 st spray of Nano P at 14 DAS + 2 nd spray of Nano P at 28 DAS	64.28	21.12	238.21
T ₁₄ : 50%RDF+ 1 st spray of Nano K at 14 DAS + 2 nd spray of Nano K at 28 DAS	62.22	20.36	237.25
T ₁₅ : 50%RDF+ 1 st spray of Nano Zn at 14 DAS + 2 nd spray of Nano Zn at 28 DAS	62.02	20.01	236.53
SEm±	2.62	1.01	4.81
CD(P=0.05)	7.59	2.94	13.94

100% RDF= Recommended dose of fertilizer- 90 kg N, 60 kg P₂O₅, 35 kg K₂O and 25 kg ZnSO₄ ha⁻¹; 75% RDF= Recommended dose of fertilizer- 67.5 kg N, 45 kg P₂O₅, 26.25 kg K₂O and 18.75 kg ZnSO₄ ha⁻¹ and 50% RDF= Recommended dose of fertilizer- 45 kg N, 30 kg P₂O₅, 17.50 kg K₂O and 12.5 kg ZnSO₄ ha⁻¹

al., 2015; Mer and Ama, 2014). Similarly in chickpea, foliar spray of NPK nano-fertilizers also increased the yield and yield components as a result of increased activities of growth hormone and enhanced metabolic processes, which tend to increase flowering and grain formation (Drostkar et al., 2016). Similar results were also reported by Abdel-Aziz et al. (2018) who found that foliar spray of nano NPK increased the growth and yield of wheat. Marzouk et al. (2019) also reported that foliar application of zinc nano-fertilizer enhanced the vegetative growth and yield attributes, yield and nutritional value of snap bean significantly compared with other nano micronutrients (Fe and Mn).

Application of foliar spray of nano-fertilizer significantly enhanced the phosphorus, potassium and zinc uptake by wheat (Table 2). The maximum P, K and Zn uptake by grain and straw (17.58 and 14.84 kg ha⁻¹, 28.54 and 101.10 kg ha⁻¹ and 330.32 and 305.88 g ha⁻¹, respectively) were recorded under the treatment T9 (100% RDF + 1st spray of Nano Zn at 14 DAS + 2nd spray of Nano Zn at 28 DAS) followed by T10 (75% RDF + 1st spray of Nano P at 14 DAS + 2nd spray of Nano P at 28 DAS), T7 (100% RDF + 1st spray of Nano P at 14 DAS + 2nd spray of Nano P at 28 DAS), T8 (75% RDF + 1st spray of Nano K at 14 DAS + 2nd spray of Nano K at 28 DAS) and T12 (75% RDF + 1st spray of Nano Zn at 14 DAS + 2nd spray of Nano Zn at 28 DAS) as compared to control. It may be due to better release and uptake of phosphorus, potassium and zinc from nano-fertilizers than conventional fertilizers. Soliman et al. (2016) concluded that the application of nano-phosphatic fertilizer exposes the plant nutrient (NPK) to

larger surface area than can enhance the fixation of plant nutrient of nano-particle, minimizing the loss at later stages of crop growth when the plant requires it. Kaviani et al. (2016) observed that foliar application of nano-fertilizers had significant positive effects on leaf N, P, K contents in heated plants as compared to control. Kumar et al. (2014) and Shrivastava et al. (2017) also confirm the findings of the present study. Sarkar et al. (2013) observed that application of nano-phosphatic fertilizer significantly increased the phosphorus concentration and uptake in pearl millet. Hanif et al. (2015) reported that phosphorus uptake per plant was increased five-folds with respect to the control due to direct entry of nano-particles in the plant being able to trigger metabolic activity contributing and enhanced exudation leading to acidification. Subsequently, desorption of Po₄³⁻ occurs through a ligand exchange reaction upon plant root exudation, possibly altering the adsorption desorption equilibrium and releasing phosphorus into soil solution which is readily available for uptake. Hussien et al. (2015) observed that synthetic apatite nano-particles can hypothetically supply sufficient phosphorus to crops throughout during growth period.

The present results are in close conformity with Kaviani et al. (2016) and Togas et al. (2017). Use of nano-fertilizer @1000 mg l⁻¹ helps to increase the concentration of micronutrients in roots and shoots of lettuce plants as reflected in plant growth (Roosta et al., 2017). These results indicate that nano-composite NPK fertilizers mitigate the increase in plasma membrane permeability and cell mortality under the effect of nano-particles in

wheat plants (Du et al., 2011). Similar results were reported by Wang et al. (2013) in watermelon plant after foliar uptake of nano-composite. Application of foliar spray of nano-fertilizer significantly increased the soil microbial population (bacteria and fungi) and microbial biomass-C in soil after crop harvest (Table 3). A significant maximum microbial count of bacteria (78.54×10^6), fungi (34.25×10^4) and microbial biomass-C ($259.33 \text{ mg kg}^{-1}$) was obtained under the treatment 100% RDF + 1st spray of Nano P at 14 DAS + 2nd spray of Nano P at 28 DAS followed by 100% RDF + 1st spray of Nano K at 14 DAS + 2nd spray of Nano K at 28 DAS, 100% RDF + 1st spray of Nano Zn at 14 DAS + 2nd spray of Nano Zn at 28 DAS as compared to control. Nano-fertilizers stimulated the growth of microbes by providing nutrients in available soluble forms and directly increased the population.

Increased availability of N, P, K and Zn which is preferentially assimilated by microorganisms (Paul and Clark, 1996), but normally limited in soil, enables increase in activity of microbial biomass. Increased and toxic concentration of nanomaterial applications poses a threat to soil microbial communities (Rajput et al., 2018). However, in the present study, the application of nano-fertilizers appears to be safer and due to proper availability of nutrients improved both plant and microbial biomass. Microbial activity of a soil system is affected by anthropogenic activities such as indiscriminate use of chemical. Microbial population decreases with increase in levels of contaminants (Xie et al., 2016). The enhancement in microbial population and activity in rhizosphere may also enhance nutrient mobilization and availability of nutrients for plants uptake (Pandey et al., 2010).

Based on the above results, it can be concluded that foliar application of nano-fertilizers not only improves the yield but also improves the soil microbial population and microbial biomass-C in the post harvest status of soil. Nano-fertilizers can serve as an efficient nutrient delivery system thereby reducing the quantity of nutrients required, soil enzymes are considered as the best indicator of microbial diversity of a soil and increases the effectiveness of applied nutrients as well as nutrients in the labile pool. The results reported here bring to light the possibility of using nano-fertilizers to deliver essential nutrients to crop plants more safely and efficiently in environmentally favourable manner.

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Add-on Information

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