Research Article

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Synergistic and antagonistic effects of soil applied P and Zn fertilizers on the performance, minerals and heavy metal composition of groundnut

Abstract: Nutrients use efficiency of plants could be affected by the antagonistic or synergistic effects of two or more elements in the soil leading to decreased or increased yield. Field experiments were conducted in 2017 and 2018 cropping seasons at the Landmark University Teaching and Research farm, Omu-Aran, Nigeria, to determine the interaction between zinc (Zn) and phosphate (P) fertilizers on growth, yield, nutrient elements and some heavy metals composition of groundnut grown on an Alfisol. Treatments consisted of four levels of phosphorus (0, 40, 80 and 120 kg P ha^{-1}) and three levels of zinc (0, 4 and 8 kg Zn ha^{-1}). The experiment was laid out in a Randomized Complete Block Design (RCBD), replicated four times. The following parameters were taken: plant height, plant spread, total biomass, number of pods/plot, weight of pods/plot, number of seeds/plot, weight of seeds/plot. Laboratory analysis of some chemical constituents of groundnut seed was carried out to determine the nutrient and heavy metals composition. Results indicated that application of 8 kg Zn ha^{-1} and 120 kg P ha^{-1} had a synergistic effect on the growth parameters and antagonistic effect on the yield, yield parameters, some nutrient elements and beneficial heavy metals. Application of 8 kg Zn and 80 kg P ha^{-1} is therefore recommended on an Alfisol without necessarily increasing the concentration of non-beneficial heavy metals in groundnut seed.

Keywords: Interaction; Micronutrient; Phosphorus; Yield; Quality; Groundnut

1 Introduction

Groundnut is an important food and cash crop in West Africa. One of the largest producers of groundnut is Nigeria. It is either grown for its nut, oil or its vegetative residue (haulms). In northern Nigeria where the crop is mostly grown, Kaduna, Kano, Adamawa, Niger, Bauchi, Bornu and Taraba states, accounted for close to 80% of the total production (Abalu and Harkness 1979).

The crop has several agronomic values which include drought tolerant and ability to produce some yield in soils that are too poor for cultivation of other leguminous crops like common beans (Anchirinah et al. 2001; Azam-Ali et al. 2001). Most of the cultivated areas in Africa are poor sandy soils using high rates of chemical fertilizers. Groundnut provides livelihood to many African farmers and it is known to provide cheap sources of quality protein (22-30%) and oil (42- 52%) on the basis of dry seed analysis (Asibuo et al. 2008), rich source of P, Ca, Mg and P (Savage and Keenan 1994).

P element is an essential macro-nutrient needed for crop growth and high yield. It is mainly supplied through chemical fertilizer application (George and Richardson 2008). P fertilizer is also needed in many plant vital processes such as photosynthesis, root formation and nitro-

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gen fixation (Grant et al. 2000), energy transformation and seed formation (Asibuo et al. 2008)

Studies have shown that majority of the world soils are deficient in zinc. Yield loss and reduction in the nutritional quality of crops have been accounted for by micronutrient (Zn) deficiency in soils and crops worldwide (Sillanpää 1982). Aboyeji et al. (2019) found that the effect of zinc was not significant on the vegetative parameters, but application of 8 kg Zn·ha^{-1} significantly increased number of seeds, weight of seeds, seed yield per hectare, and seed quality. It is estimated that almost half of the soils in the world are deficient in zinc. Zn is known to be one of the eight essential micronutrients needed for plants growth and development.

When the response of plants to one nutrient increases with an increase in the level of the other nutrient, the interaction is said to be positive and the nutrients are said to be synergistic. Conversely, when the response to one nutrient decreases with an increase in the level of the other nutrient, the interaction is said to be negative and the two nutrients are said to be antagonistic (Gomez and Gomez 1984).

P and Zn are both essential nutrients needed for plant growth, but their combined effect at a certain level could be antagonistic especially when the application of soil-P is higher. Higher application of P may cause slower uptake of Zn by the plants or inadequate of Zn in the soil (Mengel and Kirkby 1987), this process results in yield decline in many crops.

Heavy metals have high atomic number and are toxic substances even at low concentrations (Martinez and Tabatabai 1997). These elements are regarded toxic (Wolnik et al. 1993) and classified as carcinogenic (Oymen et al. 2015). The major routes of heavy metal inputs to agricultural soils include atmospheric deposition, sewage sludge, animal manures, agrochemicals and inorganic fertilizers (Nicholson et al. 1998). Losses occur through uptake in crops or livestock products, leaching and soil erosion.

Phosphorus is an important element that interferes with zinc uptake, as zinc uptake by plants reduces by increasing phosphorus in soil. High levels of phosphorus may decrease the availability of zinc or the onset of zinc deficiency associated with phosphorus fertilization may be due to plant physiological factors. One of the causes of the current stagnating yield levels is the deficiency or imbalance of nutrients resulting from nutrient antagonisms (Lobell 2009). Zn and P fertilizers are both essential in crop production but the application of the two fertilizers may have antagonistic and synergistic effects at a particular rate. The study was therefore conducted to determine the levels of interaction of Zn and P fertilizers on the performance, yield, some minerals and heavy metals composition of groundnut grown on an Alfisol of derived guinea savanna.

On the basis of this objective, it was hypothesized that, the interaction of Zn and P fertilizers would have effect on the performance, minerals and heavy metal composition of groundnut. Experiments were therefore carried out to validate this hypothesis; which level of combined or sole applications of Zn and P would improve performance, increase yield and mineral elements without necessarily increasing the heavy metals composition of the test crop grown on an Alfisol.

2 Materials and Methods

2.1 Description of Experimental Site

The experiment was carried out during 2017 and 2018 cropping season at the Teaching and Research Farm of Landmark University, Omu-aran, Kwara state (latitude 8°8'N and longitude 5°6'E) located in the transitional rainforest area with rainfall extending between April and October. An annual rainfall of 600 mm-1500 mm is predominant, following a dry season between November and March.

2.2 Pre-Cropping Soil Analysis

Pre-cropping soil samples were randomly taken from each plot and bulked to obtain composite sample for laboratory analysis.

2.3 Treatments and Experimental Design

Treatments include four levels of phosphorus (0, 40, 80 and 120 P kg ha^{-1}) and three levels of zinc (0, 4 and 8 kg ha^{-1}), which were combined as follows P_0Zn_0 (T1), $P_{40}Zn_0$ (T2), $P_{80}Zn_0$ (T3), $P_{120}Zn_0$ (T4), P_0Zn_4 (T5), $P_{40}Zn_4$ (T6), $P_{80}Z_4$ (T7), $P_{120}Zn_4$ (T8), P_0Zn_8 (T9), $P_{40}Zn_8$ (T10), $P_{80}Zn_8$ (T11), $P_{120}Zn_8$ (T12). The experiments were laid out in a Randomized Complete Block Design (RCBD), replicated four times.

2.4 Plot Size

The size of each plot in the experiment was 4 m × 4.5 m = 18 m^2 and there were 12 plots per replicate (18 m^2 × 12

= 216 m²). The size of the whole experimental plot was 216 m² × 4 = 864 m².

2.5 Seed Variety

The seed variety used for the experiment was Samaru 61 which requires between 120 and 140 days to mature and are more suited and commonly grown in the derived savanna of Nigeria.

2.6 Cultural Practices

The total experimental area was ploughed once to a depth of about 20 cm, harrowed twice to give a fine tilth and made into ridges of 0.75 m apart. Thereafter the field layout was carried out to mark out the appropriate number of treatment plots. Seeds were sown manually at inter and intra row spacing of 0.75 m × 0.2 m, at three seeds per hole which was later thinned to two stands per hole two weeks after sowing.

Phosphorus fertilizer (SSP 18%) was applied at sowing. Nitrogen fertilizer was applied at the rate of 20 kg N ha⁻¹ as basal application to all plots to facilitate vegetative growth. Nitrogen fertilizer (urea 46%) and zinc fertilizer in form of Zinc Sulphate ($ZnSO_4.7H_2O$) were applied at two weeks after sowing. All fertilizer applications were done by side placement based on treatments.

Metolachlor which is a pre-emergence herbicide suitable for groundnut was applied at the rate of 1.5 kg a.i ha⁻¹ using a knapsack sprayer and thereafter it was supplemented with manual weeding three weeks after sowing.

Harvesting was manually done at 24 weeks after sowing by carefully pulling and using hoe to dig up the groundnut from the soil. The pods were separated from the biomass and measurements were taken on both parameters based on treatment.

2.7 Observation and Data Collection

Parameters taken in both years of the experiments are as follows- Plant height and plant spread were taken at 4, 6 and 8 weeks after sowing (WAS) using a meter rule, total biomass, weight of pods/plot and weight of seeds/plot were determined at harvest by weighing on a top loading balance while number of pods/plot and number seeds/plot were determined by counting.

2.8 Laboratory analysis of mineral elements and heavy metals determination of groundnut Seeds

Representative seed samples were collected per treatment to determine the level of mineral elements and heavy metals in the seed. Seeds collected were oven dried for 24 h at 65°C after which it was grinded in a Willey mill. These samples were analysed for P, K, Ca, and Mg as recommended by the Association of Official Analytical Chemists (AOAC, 2003). Atomic absorption spectrophotometer was used to determine values for P, K, Ca, and Mg. Dry ashing of samples was carried out using the procedure as described by (Chapman and Pratt 1961) while atomic absorption spectrophotometer as described by (AOAC, 2003) was used to determine the concentration of heavy metals (Zn, Cu, Cd, Fe, Cr and Mn) using the following calculation:

$$\text{Heavy metals (mg/kg)} = \frac{\text{Titre value from machine} \times \text{volume used}}{\text{Molar mass}}$$

2.9 Data Analysis

Means for each data collected in 2017 and 2018 cropping seasons were computed after which it was subjected to statistical analysis of variance (ANOVA) using the SAS computer package version 9.0 (SAS Institute, 2002) statistical software. Treatment means were compared using Duncan Multiple Range Test (DMRT) at 0.05 level of probability.

Ethical approval: The conducted research is not related to either human or animal use.

3 Results

3.1 Initial Soil Properties

The pre-planting soil analysis is as shown in Table 1. The pH of the soil was strongly acidic, the N and Zn content were low, available P and exchangeable K were at moderate while the exchangeable Ca, Mg, organic carbon and organic matter were all adequate. The soil was high in sand with relatively low values in both silt and clay; hence the textural class Sandy loam.

3.2 Effect of Zn and P fertilizers on the vegetative growth of groundnut

The main and interaction effect of Zn and P fertilizers on plant height and plant spread are shown in Table 2. At all weeks after sowing (WAS), the effect of varying rates of Zn did not affect plant height and plant spread significantly.

Application of 120 kg P ha^{-1} significantly increased plant height at 6 and 8 WAS though statistically similar with application of 80 kg P ha^{-1}. There was no significant difference in the application of 0 and 40 kg P ha^{-1} at 6 and 8 WAS and at all rates of P at 4 WAS.

There was no significant interaction between Zn and P fertilizers on both plant height and plant spread.

3.3 Effect of Zn and P fertilizers on the yield and yield parameter of groundnut

Tables 3 shows the effects of main and interaction of Zn and P fertilizers on the total biomass, number of pods/plot, number of seeds/plot, weight of pods/plot, weight of seeds/plot and yield/ha^{-1}. The effect of application of Zn and P fertilizers was not significant on total biomass. Number of pods/plot, number of seeds/plot, weight of pods/plot, weight of seeds and seed yield increased with increasing rates of Zn fertilizer. Higher values for the parameters were observed at 8 kg Zn ha^{-1} while the least values were at the control.

Table 1: Soil physical and chemical property prior planting (0-15cm)

Parameter	2017	2018	Parameter	2017	2018
Sand (%)	76.12	75.00	O.C	32143	21186
Silt (%)	12.00	31382	K (cmol/kg)	0.29	0.33
Clay (%)	32448	42339	Ca (cmol/kg)	44106	44593
Textural class	Sandy loam	Sandy loam	Mg (cmol/kg)	0.32	0.41
pH (H2O) 1:1	45778	14397	Available phosphorus (mg/kg)	44175	20394
Total N (%)	0.16	0.13	Zn (mg/kg)	0.45	0.45
O.M (%)	43954	20486			

Table 2: Effect of Zn and P fertilizers on plant height and spread of groundnut based on the mean from 2017 and 2018 cropping seasons

	Plant height			Plant spread		
Treatments	**4 WAS**	**6WAS**	**8WAS**	**4WAS**	**6WAS**	**8WAS**
Zinc (Zn) kg ha^{-1}						
0	17.05a	20.22a	20.14a	29.59a	35.56a	36.50a
4	17.62a	21.47a	21.70a	31.00a	37.17a	38.70a
8	17.87a	21.87a	21.89a	31.70a	38.36a	39.80a
Phosphorus (P) kg ha^{-1}						
0	16.07a	19.07b	18.74b	32.58a	34.44b	36.10b
40	17.25a	19.48b	19.67b	29.20a	33.54b	38.55b
80	17.57a	22.04a	22.37ab	29.20a	37.41ab	40.69ab
120	19.14a	21.18a	24.35a	32.20a	42.67a	45.85a
Interaction						
Zn	ns	ns	ns	ns	ns	Ns
P	ns	*	*	ns	*	*
Zn*P	ns	ns	ns	ns	ns	Ns

Means in a column under any given treatment followed by the same letter(s) do not differ significantly at 0.05 level of probability using the Duncan Multiplication Range Test (DMRT). ns = not significant, * = significant at 0.05 level of probability

Table 3: Effect of Zn and P fertilizers on the yield and yield parameters of groundnut based on the mean from 2017 and 2018 cropping seasons

Treatments	Total biomass/ plot (kg)	Number of pods/plot (kg)	Weight of pods/plot (kg)	Number of seeds/plot (kg)	Weight of seeds/plot (kg)	Yield t/ha
Zinc (Zn) kg ha^{-1}						
0	92.58b	31.25c	31.66c	47.76c	22.47c	1798c
4	110.75a	32.30b	33.81b	49.95b	24.94b	1995b
8	117.61a	33.03b	34.94a	51.25a	25.83a	2066a
Phosphorus (P) kg ha^{-1}						
0	98.24b	21.93c	28.59c	19.65c	19.65c	1572c
40	103.88b	34.20b	34.81b	25.70b	25.70b	2056b
80	116.61a	36.36a	35.71a	26.78a	26.78a	2142a
120	106.19b	36.30a	34.77b	25.52b	25.52b	2042b
Interaction						
Zn	*	*	*	*	*	*
P	*	*	*	*	*	*
Zn*P	*	*	*	*	*	*

Means in a column under any given treatment followed by the same letter(s) do not differ significantly at 0.05 level of probability using the Duncan Multiplication Range Test (DMRT). ns = not significant, * = significant at 0.05 level of probability

Increasing rates of P fertilizer from 0 to 80 kg P ha^{-1} significantly increased the yield and yield parameters. Further increase in P fertilizer to 120 kg P ha^{-1} reduced values for the parameters. The least value for yield and yield parameters were observed at the control. Interaction was significant on the yield and yield parameters and the best combination for optimum performance of groundnut was 8 kg Zn ha^{-1} and 80 kg P ha^{-1}.

3.4 Effect of Zn and P fertilizers on the concentration of nutrient elements on groundnut seed

The effects of the treatments on the concentration of P, K, Ca, and Mg are as presented in Table 4. Increasing rates of Zn from 0 kg Zn ha^{-1} to 8 kg Zn ha^{-1} significantly increased the availability of all the nutrient elements, except P where increasing levels of Zn resulted in reduced, but had statistically similar values.

Varying rates of phosphorus fertilizer resulted in varying nutrient concentration in groundnut seed. There was no significant effect of application of phosphorus fertilizer on K concentration of the seeds. Increasing rates of phosphorus fertilizer up to 80 kg P ha^{-1} significantly increased the seed concentration of P, Ca and Mg. Further increase to 120 kg P ha^{-1} did not increase the values significantly. P and Zn interactions had significant effects on the concentration of all the nutrient elements and the best

combination was 8 kg Zn ha^{-1} and 80 kg P ha^{-1} which was statistically similar to 8 kg Zn ha^{-1} and 120 kg P ha^{-1}.

3.5 Effect of Zn and P fertilizers on some heavy metals in groundnut seed

Table 5 present data on the effect of application of Zn and P fertilizers on Fe, Cu, Mn, Cd, Cr and Zn concentration of groundnut seed. There was no significant effect of the application of Zn on the concentration of Fe and Cu on groundnut seed. Application of zinc fertilizer up to 8 kg Zn ha^{-1} significantly reduced values for Mn, Cd and Cr but increased the concentration of Zn. Concentration of Fe, Cu and Mn in groundnut seeds increased significantly with the application of 120 kg P ha^{-1}. Significant interaction between Zn and P fertilizers was observed on all the heavy metals except Fe and Cu. Zn and P interaction was significant on Mn, Cd, Cr, and Zn while the best combination was 8 kg Zn ha^{-1} and 80 kg P ha^{-1}.

4 Discussion

Constraints to groundnut production in Nigeria may be due to deficiency of macro and micronutrients and possibly due to nutrients interactions and or poor nutrient retention ability of the soil. One of the most important

Table 4: Effect of Zn and P fertilizers on the concentration of nutrient elements (mg kg^{-1}) in groundnut seed based on the mean from 2017 and 2018 cropping seasons

Treatments	P	K	Ca	Mg
Zinc (Zn) kg ha-^{1}				
0	218.58a	0.31b	1.38b	1.77b
4	217.58a	0.31b	1.52b	2.37a
8	216.21a	0.33a	1.69a	2.40a
Phosphorus (P) kg ha^{-1}				
0	178.67bb	0.33a	1.25c	1.94b
40	197.36b	0.32a	1.49b	1.96b
80	210.55a	0.31a	1.62ab	2.30a
120	209.76a	0.32a	1.76a	2.33a
Interaction				
Zn	*	*	*	*
P	*	*	*	*
Zn*P	*	*	*	*

Means in a column under any given treatment followed by the same letter(s) do not differ significantly at 0.05 level of probability using the Duncan Multiplication Range Test (DMRT). ns = not significant, * = significant at 0.05 level of probability

fertilizer management strategies towards improving crop response to application of fertilizer is to understand or identify synergisms and antagonisms of different types of nutrient elements.

Synergism nutrient interaction is synergistic where the yield due to the combined application of two nutrients is more than the yield expected on the basis of the effects from the individual applications of the nutrients; while antagonism nutrient interaction is antagonistic where the yield due to the combined application of two nutrients is less than the yield expected on the basis of the effects from the individual applications of the nutrients (René et al. 2017). Nutrient imbalance or interaction in crops is probably one of the most important factors affecting yields of annual crops (Fageria et al. 2014).

Application of varying rates of Zn and P on groundnut revealed that the two nutrients have effect on the vegetative growth (plant height, plant spread), yield, yield parameters, nutrient concentration and heavy metals accumulation of groundnut. Application of Zn increased plant height and spread though the effect was not significant on the parameters. Increase in the vegetative parameters may be due to that Zn encourages the vegetative growth and increased plant capacity for building metabolites. It could also be as a result of auxin production by the plants which facilitated production of more plant cells. Similar findings were from Tomar et al. (1990); Saxena and Chandel (1997) where they reported that auxin and better dry matter production are indicators that application of Zn enhanced the plant growth.

P is essentially required for healthy growth with efficient root system and profuse nodulation which in turn can affect the N_2-fixation potential (Kwari 2005). P is considered as a limiting factor in plant nutrition due to the deficiency of available soluble phosphate in the soil (Uma Maheswar and Sathiyavani 2012). Application of P fertilizer at 120 kg P ha^{-1} significantly increased plant height and spread though statistically similar with the application of 80 kg P ha^{-1}. The increase in the vegetative growth of groundnut resulting from the application of P fertilizer could be ascribed to the moderate level of available P in the soil which may not be able to sustain the crop to maturity. It could also be as a result of the beneficial effects of phosphates in the process of photosynthesis, nitrogen fixation and other vital physiological processes. The non- or zero interaction between Zn and P on the vegetative parameters could be that the applied rates for the two nutrients were adequate for the vegetative growth of groundnut.

Deficiency of soil Zn is common in many climatic regions, particularly in sandy soil where it causes yield decrease and low yield quality of groundnut. Zn functions in plants are activity related. Zn activates many plant enzymes such as auxin which assists in producing more cells and dry matter thus yield increase (Devlin and Withan 1983).

Significant increase in yield and yield parameters as a result of application of 8 kg Zn ha^{-1} could be ascribed to the improved vegetative growth which facilitated production of a greater number of nodules and in turn increased pod yield as a result of increased rate of photosynthesis and sufficient nutrient availability. These results agree with those of Helpyati (2001) and Sumangala (2003).

The increases in yield and its attributes may be due to the fact that phosphorus is known to help in the development of more extensive root system (Kamara et al. 2011) and thus enables plants to absorb more water and nutrients from the depth of the soil. This in turn could enhance the plant's ability to produce more assimilates which are reflected in the high biomass production. Application of P, Ca and B fertilizers increased nutrients availability to the crop during the growing season which leads to greater utilization of assimilates into the pods and ultimately increased number of filled pods and shelling percentage (Kamara et al. 2011). In a similar experiment, El-Desouky et al. (1999) found that application of P fertilizer increased number and weight of nodules, N-activity and yield of groundnut.

The result also indicated that zero application of phosphorus fertilizer resulted in the least values for yield and all the yield parameters. This could be ascribed to reduction in biomass, poor root nodulation and development which may affect nitrogen fixation. Kwari (2005) reported that, *rhizobia* population and legume root development are a function N$_2$ fixing potential.

Interaction of application of Zn and P fertilizer on yield and yield parameters revealed that there was synergistic effect of the two fertilizers at 8 kg Zn ha^{-1} and 80 kg P ha^{-1}. Antagonistic effect was observed when there was reduction in values for yield and yield parameters at the application of 120 kg P ha^{-1}. This could be attributed to decrease in Zn uptake which precipitated when P was applied, this reaction will make Zn not to be available to the crops. Zinc can also get precipitated as Zn phosphate on addition of phosphate fertilizers (Lambert et al. 2007). It could also be that at 120 kg P ha^{-1} plants have accumulated excess P thereby causing reduced Zn uptake (Salimpour et al. 2010).

Zinc is a cation that interacts with all plant nutrients in the soil or as anions when absorbed by plants. There was a significant interaction between Zn and P on the concentration of P, K, Ca and Mg on groundnut seeds. Results showed that application of Zn and P fertilizers at 8 kg Zn ha^{-1} and 80 kg ha^{-1} respectively resulted in synergistic effect which made the nutrients elements (P, K, Ca and Mg) available to groundnut.

Plants are capable of absorbing range of necessary nutrient elements from the soil as micronutrients. The soil contains essential heavy metals (Fe, Cu, Mn, Cr, Cd, Zn, As e.t.c) necessary for plant growth and development. Accumulation of heavy metals in plants could result in growth inhibition and toxicity (Hall 2002; Lasat 2002).

Application of Zn fertilizers reduced values for all the heavy metals in groundnut seeds except Zn. Reduction in values of these heavy metals could be attributed to antagonistic effect of Zn. Concentration of Fe increased in plant shoot that are deficient in Zn (Imtiaz et al. 2003). Chaudhry et al. (1973) reported an antagonistic response on rice yield of the Cu x Zn interaction. Zn and Cd compete for uptake and translocation by plants, P-fertilizers contains Zn as contaminants which may reduce accumulation of Cd in crops (Grant 2011).

Superphosphate fertilizers contain in addition to nutrient elements trace metal impurities like Cd, Pb or Hg (Oyedele et al. 2006). Among the contributors of heavy metals into agricultural soils are P-fertilizers. This study revealed that application of 120 kg P ha^{-1} increased the concentration of all the heavy metals in groundnut seed. This could be as a result of impurities present in P fertilizer. Phosphate rock on the average is known to contain sizable quantity of As, Cd, Cr, Cu, Pb and Zn in the range of 11, 25, 188, 32, 10, and 239 mg kg respectively (Mortvedt and Beaton 1995). Thomas et al. (2012) in their experiment concluded that, the increase in the concentration of the heavy metals in the soil after the experiment shows that phosphate fertilizers contribute greatly to heavy metal content in soils.

The results revealed that application of Zn and P fertilizers had interaction effects on the availability of heavy metals in the soil and that all the heavy metals detected from the seeds were within the permissible limits as recommended as recommended by (FAO/WHO, 2010).

5 Conclusion

Application of 8 kg Zn ha^{-1} and 120 kg P ha^{-1} showed synergistic effect on the vegetative parameters and this was similar to the application of 8 kg Zn ha^{-1} and 80 kg P ha^{-1}. The interaction of Zn and P also showed synergistic effect on the yield and yield parameters when 8 kg Zn ha^{-1} and 80 kg P ha^{-1} was applied and antagonistic effect when 8 kg Zn ha^{-1} and 120 kg P ha^{-1} was applied. Therefore application 8 kg Zn ha^{-1} and 80 kg kg P ha^{-1} will be adequate for improved yield, yield parameters and nutrients availability without

increasing the heavy metals concentration of groundnut seed grown on an Alfisol.

Conflict of interest: Authors declare no conflict of interest.

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