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POTASSIUM AND NANO-COPPER FERTILIZATION EFFECTS ON MORPHOLOGICAL AND PRODUCTION TRAITS OF OAT (*AVENA SATIVA* L.)

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SUMMARY

Potassium is the third essential nutrient of commercial fertilizers, which strengthens plants' abilities to resist diseases and plays a vital role in increasing crop yields and overall quality. Nanofertilizers offer benefits in nutrition management through their strong potential to increase nutrient uptake efficiency and release nutrients very slowly compared with conventional fertilizers. Potassium fertilizer and nano-copper fertilization effects on oat (*Avena sativa* L.) morphological and yield traits have been studied in the spring season 2020–2021 at the Department of Field Crops, College of Agriculture, University of Kerbala, Iraq. The said study conducted research with two factors, viz., potassium fertilizer levels (0, 80, and 160 kg ha^{-1}) and nano-copper concentrations (0, 30, and 60 mg L^{-1}) in a randomized complete block design (RCBD) with three replications. Potassium fertilization at the rate of 160 kg ha^{-1} produced the highest mean number of tillers, spikes m^{2}, 1000-grain weight, biological yield, grain yield, and harvest index, with average values of 510.37 tillers m^{-2}, 438.99 spikes m^{-2}, 41.14 g, 26.52 ton ha^{-1}, 5.85 ton ha^{-1}, and 22.00%, respectively. The nano-copper application at the concentration of 60 mg L^{-1} followed by the values of 478.13 tillers m^{-2}, 418.87 spikes m^{-2}, 36.91 g, 4.69 ton ha^{-1}, 25.25 ton ha^{-1}, and 22.02%, respectively. The combined use of potassium (160 kg ha^{-1}) and nano-copper (60 mg L^{-1}) proved more effective in boosting the oat grain yield. Results revealed that the oat exhibited more favorable vegetative and productive development features after receiving potassium and nano-copper fertilization.

Keywords: Oat (*Avena sativa* L.), potassium, nano-copper, nutrients, fertilization, grain yield

Key findings: Potassium (160 kg ha^{-1}) and nano-copper (60 mg L^{-1}) fertilizations brought a significant and sustainable improvement in the morphological and yield traits and eventually in grain yield of oat.

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INTRODUCTION

Oat (*Avena sativa* L.) is a dual-purpose crop belonging to the grass family, Poaceae. Oats are grown as a cereal crop in many counties, with a global cultivated area of 9.94 million hectares and grain production of 24.95 million tons (USDA, 2022). It contains a high percentage of fibers that reduce body fat, control glucose levels, and lower cholesterol. Oats' high nutritional value, ease of cultivation, and wide adaptability distinguished them from other cereals. Furthermore, oats contain high content of vitamins, unsaturated fats, proteins,

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and antioxidants, differentiating them with high nutritional value. In addition, the distinct high proportion of fibers contained in oats sets them apart from other cereal grains (Loskutov and Khlestkina, 2021).

Aside from being a sustainable alternative to milk and other dairy products, the oat by-products are processed further to obtain renewable and sustainable chemicals for industry (Anttila *et al*., 2004; Ferranti and Velotto, 2022). In Iraq, as in other parts of the Middle East, the oat plant has a low genetic potential for yield. The inadequate attention on soil and crop activities, particularly nutrients, causes low productivity, even if favorable agricultural and environmental conditions exist. The use of modern agricultural technologies can improve oat crop productivity. Focusing on various agricultural practices, including fertilization and selection of appropriate cultivars for wide adaptability, can increase the grain and fodder yield and improve quantity and quality per unit area of oats (Kaziu *et al.,* 2019; Gargis, 2006).

Potassium is a vital macro-nutrient responsible for the stimulation of over 60 enzymes in plants that are involved in the transfer of energy, as well as, the synthesis of sugar, starch, and protein. Potassium contributes by helping transfer nutrients (nitrates) from the roots to the upper parts (grains and fruits) of a plant and transfer manufactured material from the upper plant parts to its roots. It also encourages the division of cells and the formation of proteins through an activated enzyme cycle. It also plays a significant role in regulating the osmotic effort of plant cells and stimulating the formation of plant hormones, such as, cytokinins. Crop plants require cytokinins in large quantities as it increases the efficiency of other fertilizers, and its deficiency leads to a decline in production with poor quality, causing high susceptibility to pest infestation (Al-Khafaji *et al*., 2000; Mohammed et al., 2021; Johnson *et al*., 2022).

In recent years, nanotechnology is regarded as a potentially useful tool for enhancing a wide variety of agricultural commodities. Enhancing the management and maintenance of inputs in field production lower the costs of inputs, such as, fertilizers and pesticides. In addition, nanotechnology prevents side effects caused by the accumulation of unwanted substances in the soil, as well as, the slow nutrient decomposing, hence preserving the environment at a faster rate of impact and distribution to the target area (Khan *et al*., 2017***)***. The "smart delivery system" method refers to nanotechnology providing plants with nourishment in a methodical and pollution-free manner. This method involves directing fertilizers to the exact locations in the soil where required (Nair *et al*., 2010). Nano fertilizers are essential in plant nutrition, being more soluble, active, and able to penetrate and enter into different plant tissues and transfer compounds to the target places, such as, roots, fruits, leaves, and other plant parts, but in small quantities compared with other fertilizers (Mastronardi *et al*., 2015). Copper is one of the elements that plants need to make chlorophyll and protein. A lot of copper is found in the chloroplasts, and it also helps make enzymes like ascorbic acid oxidase and cytochrome oxidase. Copper is a part of the enzymes, phenolases and laccase, which are important for oxidation-reduction reactions in plants. Copper is also a part of the synthesis of the enzyme, catalase and a part of the chain of electronic transport that links the two photochemical reaction systems needed for photosynthesis (Ali *et al*., 2014).

Given the economic importance of the oat crop, researchers are very interested in increasing its production coupled with good quality. No studies on the nano-copper application and its interaction with potassium fertilization have been carried out so far, particularly in Iraq. This study aimed to determine the varied effects of three different levels of potassium and nano-copper fertilizations on oat production.

MATERIALS AND METHODS

Experimental procedure and crop farming

During spring 2020–2021, a field experiment on oat variety 'Shfa'a' was carried out in silty loam soil at the Department of Field Crops, College of Agriculture, University of Kerbala, Iraq (Table 1). The research aimed to examine how different potassium fertilizer levels and nano-copper concentrations affected the oat morphological and yield related traits. Potassium fertilizer levels (0, 80, and 160 kg ha^{-1}) and nano-copper concentrations (0, 30, and 60 mg L^{-1}) were tested with three replications using a randomized complete block design. Each experimental unit consisted of 10 rows of oats, with 3 m in length, 20 cm row spacing, and 5 cm seed depth. A seed rate of 140 kg ha^{-1} (Majid and Ibrahim, 2017) was utilized for this experiment.

The crop was irrigated right away following the planting process, and it received

Table 1. Chemical and physical properties of the study soil at a depth of 0–30 cm before oat planting.

Properties		Values
pH		7.31
EC		dS m^{-1}2.81
OM		g kg^{-1}1.28
N available		0 mg kg^{-1}16.3
K available		1 mg kg^{-1}29.2
P available		mg kg^{-1}8.62
Cu available		1.40 mg kg^{-1}
Soil separators	Sand	g kg^{-1}111
	Silt	g kg^{-1}641
	Clay	g kg^{-1}248
Texture		Silty loam
Bulk density		Mg m^{-3}1.32

additional watering as required throughout the growing season. Hand weeding was done as needed throughout the season. Nitrogen and phosphorus were applied on soil at the rate of 200:80 kg ha^{-1}. Potassium was added sequentially during the stages of germination (ZG 0.0), tillering (ZG 2.1), and flowering (ZG 6.1) in the form of K_2SO_4 (K 41.5).

Spraying solutions of the copper were prepared according to the required concentrations. The first spray of nano-copper was carried out at the vegetative stage and the formation of tillers, while the second spray was made at the beginning of the flowering and heading (Al-Abidi, 2011). Spraying was carried out using the hand sprinkler in the early morning hours, and the control treatment was sprayed with water. On 25 May 2022, once the oat crop reached physiological maturity and had exuded its maximum amount of material, the crop was harvested at the end of the growing season.

Data recorded

In each experimental unit, determining the plant height in centimeters started from the soil surface to the tip of the spike excluding the awns, and taking the average of ten plants. Likewise for each experimental unit, the tillers per square meter were counted and averaged. In addition, the harvested spikes per square meter were also tallied. The 1000-grain weight, measured in grams, was taken from 20 wheat seed samples that were randomly chosen from each experimental unit, and then averaged. For biological and grain yield, the crop in each experimental unit's square meter was harvested, dried, threshed, and then converted to tons per hectare. The harvest index (%) was also calculated by the following formula:

$$\text{Harvest index} = \frac{\text{Grain yield per plant}}{\text{Biological yield per plant}} \times 100$$

Statistical analysis

All the recorded data for various traits were statistically analyzed as per potassium by nano-copper interaction analysis (Gomez and Gomez, 1984). After getting the significant variations among the different mean categories, the means for each parameter were further separated and compared by using the least significant difference (LSD) test at a 5% level of probability. The statistics software GenStat12 was employed.

RESULTS

According to the analysis of variance (ANOVA), the potassium fertilizer levels, nano-copper concentrations, and interactions of potassium fertilizer × nano-copper revealed significant ($P \leq 0.05$) differences for the majority of the traits (Table 2). However, the interaction effects were nonsignificant for tillers per square meter and biological yield.

Plant height

Results indicated a significant effect in different potassium levels and nano-copper concentrations on the average plant height of oats (Table 3). It was noted with the addition of potassium at the rate of 160 kg ha^{-1}, leading to a significant increase of 100.01 cm compared with the control treatment (no additional), which showed the lowest plant height (83.06 cm) for oats. Nano-copper application with a concentration of 60 mg L^{-1} showed a significant increase in the average plant height (97.67 cm) compared with the no-

Table 2. Analysis of variance with two factors (potassium fertilizer and nano-copper), and their interaction for various traits in oat.

Source of variation	d.f.	Mean squares						
		Plant height (cm)	Tillers (m^{-2})	Spikes (m^{-2})	1000-grain weight (g)	Biological yield (ton ha^{-1})	Grain yield (ton ha^{-1})	Harvest index (%)
Replications	2	189.42	748.12	631.69	83.89	18.88	0.13	2.04
Potassium fertilizer	2	180.94*	1160.10*	995.45*	63.74*	12.63*	4.93*	45.15*
Nano-copper	2	716.04*	16633.30*	12710.92*	439.58*	56.76*	32.53*	354.55*
Potassium fertilizer × Nano-copper	4	17.88*	18.41^{NS}	26.06*	4.59*	0.10^{NS}	0.90*	12.69*
Error	16	1.64	15.33	4.132	0.32	0.21	0.004	0.14

*: Significant at P≤0.05, NS: Nonsignificant

Table 3. Effect of different potassium levels and nano-copper concentrations on the plant height of oat.

Potassium levels (kg ha^{-1})	Nano-copper concentrations (mg L^{-1})			Means (cm)
	0	30	60	
0	81.13	83.04	85.01	83.06
80	91.00	95.00	103.01	96.34
160	94.00	101.04	105.00	100.01
Means (cm)	88.71	93.03	97.67	

$LSD_{0.05}$ Potassium levels = 1.27, $LSD_{0.05}$ Nano-copper concentrations = 1.27
$LSD_{0.05}$ P × NC Interactions = 2.21

spray treatment (88.71 cm). In the interaction of potassium levels and nano-copper concentrations, the results also showed a significant effect on the average values of this trait. The combination of potassium (160 kg ha^{-1}) and nano-copper (60 mg L^{-1}) was significantly superior for this trait by giving the highest value for plant height (105.00 cm). However, it was insignificant from the interaction of potassium (80 kg ha^{-1}) and nano-copper (60 mg L^{-1}) with a plant stature of 103.01 cm compared with the lowest value obtained for control (81.13 cm).

Tillers per square meter

Both potassium and nano-copper applications have impacted the tiller number of oats (Table 4). Specifically, adding potassium at 160 kg ha^{-1} exhibited a substantial increase in the tillers (510.37 tillers m^{-2}) compared with the control (424.40 tillers m^{-2}). Nano-copper application at the rate of 60 mg L^{-1} led to a significant enhancement in the average number of tillers (478.13 tiller m^{-2}) with an increase of 4.00% as compared with the control (455.43 tillers m^{-2}). However, the results revealed insignificant differences in the interactions of potassium and nano-copper levels on the said trait.

Spikes per square meter

In oats, fertilization with potassium and nano-copper showed a notable effect on the average number of spikes (Table 5). The application of potassium at 160 kg ha^{-1} resulted in a substantial increase in oat spikes (438.99 spikes m^{-2}) compared with the control treatment (367.30 spikes m^{-2}). Spraying with nano-copper at the concentration of 60 mg L^{-1} led to a significant increase in the spikes (418.87 spikes m^{-2}) compared with the control (398.20 spikes m^{-2}). In the case of interaction of potassium and nano-copper, a relevant effect was observed for spike number, and the treatment combination of potassium (160 kg ha^{-1}) and nano-copper (60 mg L^{-1}) resulted in superior outcomes for spikes (448.50 spikes m^{-2}) with an increase of 27.00% compared with control.

Table 4. Effect of different potassium levels and nano-copper concentrations on the tillers per square meter of oat.

Potassium levels (kg ha^{-1})	Nano-copper concentrations (mg L^{-1})			Means (m^2)
	0	30	60	
0	411.20	425.30	436.70	424.40
80	453.80	465.30	479.10	466.07
160	501.30	511.20	518.60	510.37
Means (m^2)	455.43	467.27	478.13	

$LSD_{0.05}$ Potassium levels = 3.91, $LSD_{0.05}$ Nano-copper concentrations = 3.91
$LSD_{0.05}$ P × NC Interactions = N.S.

Table 5. Effect of different potassium levels and nano-copper concentrations on the spikes per square meter of oat.

Potassium levels (kg ha^{-1})	Nano-copper concentrations (mg L^{-1})			Means (m^2)
	0	30	60	
0	353.10	372.50	376.30	367.30
80	411.10	425.20	431.80	422.70
160	430.40	438.07	448.50	438.99
Means (m^2)	398.20	411.92	418.87	

$LSD_{0.05}$ Potassium levels = 2.03, $LSD_{0.05}$ Nano-copper concentrations = 2.03
$LSD_{0.05}$ P × NC Interactions = 3.51

1000-grain weight

Potassium application at 160 kg ha^{-1} showed a significant effect on the average 1000-grain weight in oats (41.14 g), compared with control having the lowest 1000-grain weight (27.16 g) (Table 6). The results also showed that spraying with nano-copper at 60 mg L^{-1} concentration caused a significant increase in the average 1000-grain weight (36.91 g), compared with control (31.59 g). The combined application and interaction of potassium and nano-copper also revealed a notable effect on the average 1000-grain weight. The combination of potassium (160 kg ha^{-1}) and nano-copper (60 mg L^{-1}) was significantly effective in boosting the seed size and eventually enhanced the 1000-grain weight (44.70 g) with an increase of 88.29% compared with control.

Biological yield

Potassium and nano-copper applications in various doses and concentrations have significantly affected the average biological yield in oats (Table 7). Application of potassium at 160 kg ha^{-1} led to a significant increase in biological yield (26.52 ton ha^{-1}) compared with control (21.50 ton ha^{-1}). The results also showed that nano-copper application with the concentration of 60 mg L^{-1} significantly enhanced the biological yield (25.25 ton ha^{-1}) than the control (22.88 ton ha^{-1}). However, the interactions of potassium and nano-copper showed no significant impact on the biological yield in oats.

Table 6. Effect of different potassium levels and nano-copper concentrations on the 1000-grain weight (g) of oat.

Potassium levels (kg ha^{-1})	Nano-copper concentrations (mg L^{-1})			Means (g)
	0	30	60	
0	23.74	27.74	30.02	27.16
80	33.35	34.07	36.03	34.48
160	37.69	41.02	44.70	41.14
Means (g)	31.59	34.28	36.91	

$LSD_{0.05}$ Potassium levels = 0.56, $LSD_{0.05}$ Nano-copper concentrations = 0.56,
$LSD_{0.05}$ P × NC Interactions = 0.98

Table 7. Effect of different potassium levels and nano-copper concentrations on the biological yield of oat.

Potassium levels (kg ha^{-1})	Nano-copper concentrations (mg L^{-1})			Means (ton ha^{-1})
	0	30	60	
0	20.21	21.80	22.51	21.50
80	23.14	24.16	25.53	24.27
160	25.31	26.53	27.72	26.52
Means (ton ha^{-1})	22.88	24.16	25.25	

$LSD_{0.05}$ Potassium levels = 0.45, $LSD_{0.05}$ Nano-copper concentrations = 0.45,
$LSD_{0.05}$ P × NC Interactions = N.S.

Grain yield

The results denoted a significant effect in various potassium levels and nano-copper concentrations on the average grain yield in oats (Table 8). The potassium application at 160 kg ha^{-1} significantly increased the average grain yield (5.85 t ha^{-1}) compared with the control (2.07 t ha^{-1}) in oats. The results also showed that nano-copper application at 60 mg L^{-1} led to a significant increase in the average grain yield (4.69 Mg ha^{-1}) compared with the control treatment (3.26 Mg ha^{-1}). The results also implied that the interaction between potassium levels and nano-copper concentrations had a notable effect on the average grain yield. The combination of potassium (160 kg ha^{-1}) and nano-copper (60 mg L^{-1}) significantly led to grain yield of 6.66 t ha^{-1} and showed an increase of 243.00% compared with the control.

Harvest index

The results revealed a significant effect in different potassium levels and nano-copper concentrations on the harvest index in oats (Table 9). The application of potassium at 160 kg ha^{-1} resulted in a significant increase in harvest index (22.02%) compared with control (9.66%), which was the lowest for such a trait. Further, nano-copper spray at a concentration of 60 mg L^{-1} showed a substantial increase in average harvest index (18.12%) vs. control (13.92%). Also, the results showed a notable effect of the interaction between the potassium levels and nano-copper on the harvest index. It reveals a good combination of these fertilizers with one another. The potassium (160 kg ha^{-1}) and nano-copper (60 mg L^{-1}) interaction are superior in this characteristic, as it produced the greatest value for harvest index (24.05%) in contrast with control, which only resulted in 9.63%.

Table 8. Effect of different potassium levels and nano-copper concentrations on the grain yield of oat.

Potassium levels (kg ha^{-1})	Nano-copper concentrations (mg L^{-1})			Means (ton ha^{-1})
	0	30	60	
0	1.94	2.07	2.20	2.07
80	3.01	4.75	5.22	4.33
160	4.83	6.06	6.66	5.85
Means (ton ha^{-1})	3.26	4.29	4.69	

$LSD_{0.05}$ Potassium levels = 0.06, $LSD_{0.05}$ Nano-copper concentrations = 0.06,
$LSD_{0.05}$ P × NC Interactions = 0.11

Table 9. Effect of different potassium levels and nano-copper concentrations on the harvest index of oat.

Potassium levels (kg ha^{-1})	Nano-copper concentrations (mg L^{-1})			Means (%)
	0	30	60	
0	9.63	9.54	9.82	9.66
80	13.03	19.70	20.49	17.74
160	19.11	22.91	24.05	22.02
Means (%)	13.92	17.38	18.12	

$LSD_{0.05}$ Potassium levels = 0.37, $LSD_{0.05}$ Nano-copper concentrations = 0.37,
$LSD_{0.05}$ P × NC Interactions = 0.65

DISCUSSION

Potassium and nano-copper fertilization have a significant positive effect on plant height, as well as, the number of tillers and spikes produced per square meter in oats. These findings validate those obtained by Al-Jubouri (2010) and Al-Jubouri *et al*. (2012). They discovered that increased levels of potassium fertilization led to an increase in the average plant height in crops of the Poaceae family. The potassium causes the accumulation of carbohydrates in the stem for elongation, as well as, an increase in the number and thickness of the nodes, contributing to plant height in crop plants (Johnson *et al.,* 2022; Abu-dahi and Younis, 1988). At the start of the cropping season, an increase in plant vegetative development leads to the effective absorption of photosynthetic rays, which are necessary for the production of more sugar in the plants. Thus, it leads to more available required elements necessary for the successful emergence and creation of the tillers and spikes, eventually increasing grain yield. An increase in the plant's vegetative growth also increases the available required materials for the development during reproductive stage of the oats and barley (Usanova, 1986). This might be due to the vital role of potassium in increasing the activity of meristematic tissues in plant cells, which leads to the expansion of their walls, and thus increasing the available manufactured materials that support the emergence and continued growth of fertile tillers (Al-Dulaimi and Al-Jubour (2020).

Copper has a significant effect on the biological and physiological processes that occur within the plant, which has a positive reflection in the form of improved plant growth and enhanced production of good quality traits (Al-Nuaimi, 2000). In the context of agricultural production, the combined application of potassium fertilizer and nano-copper had a significant positive effect on the growth and yield parameters as compared with the two treatments used individually. The recent findings confirmed that increased use of potassium fertilizer in combination with nano-copper proved effective in improving morphological traits and raising the total grain yield. These relate to the potassium's contribution to increases in vigor and activity during vegetative growth, positively reflected in the increase in individual yield components (Ali *et al*., 2014). These results were consistent with the past findings of AL-Yasari and Al-Hilli (2018) and Al-Jubouri *et al*. (2012), validating the role of potassium and copper and their influence on enhancing the yield and its components.

Nano-copper application, at varying concentrations, has a considerable impact on yield attributes and grain yield. Copper is one of the essential micro-nutrients for plants that participate in many physiological processes. Its deficiency in plants leads to a decrease in and poor yield quality. This is due to a high percentage of total copper found in chloroplasts that takes part in the synthesis of chlorophyll. Its deficiency leads to a decline in the produced chlorophyll. Some enzymes, such as ascorbic acid oxidase and cytochrome oxidase, play a vital role in the cell division and the development of pollen grains, the generation of secondary meristem cells, the growth in cell thickness, and the production of chlorophyll and protein in plants (Ali *et al*., 2014). Copper also increases the activity of carbon metabolism processes by increasing the chlorophyll content in the leaves and enhancing the ability of crops to withstand biotic and abiotic stress conditions.

The increase in growth characteristics and grain yield from potassium and nano-copper fertilization may be due to the significant role of nano-fertilizers in plant nutrition (Abobatta, 2017). In addition, distinct to nano-fertilizers is their rapid absorption rate, caused by their small size and high surface area. It is because nano-fertilizers may provide a larger surface area for a cultivar of metabolic reactions that occur in plants, which in turn accelerates the rate of carbonization and stimulates the demand for nutrients (Yang *et al*., 2016). Therefore, an adequate amount of copper boosts the plant's potential to establish a robust root system capable of absorbing potassium from the soil and other minerals, thus, leading to an increase in the concentration of those nutrients within the plant. It is possible to explain the response of the oat plant to potassium and nano-copper fertilization in the characteristics of the crop to achieve a state of better nutritional balance for these nutrients within the plant. These pushed the plant towards better growth and to invest the growth factors in a better building to be more capable of development and production.

CONCLUSIONS

The study concludes potassium and nano-copper fertilization augments vegetative growth, enhancing photosynthesis for improved yield component formation and, thus, a higher grain yield in oats. The interaction of potassium (160 kg ha^{-1}) and nano-copper (60 mg L^{-1}) improved the growth and morphological traits and grain yield in oats.

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