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Effect of Zinc Levels on Soil Physico-Chemical Properties in Mint (*Mentha arvensis* L.)–Wheat (*Triticum aestivum* L.) Intercropping System under Two Land Configurations

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ABSTRACT: A field experiment was conducted during the rabi season of 2021–2022 at the Students' Research Farm, Department of Agriculture, Amritsar, to evaluate the influence of zinc application on soil properties and crop performance in a mint (*Mentha arvensis* L.)–wheat (*Triticum aestivum* L.) intercropping system under two land configurations. The study followed a split plot design with two main plot treatments (bed and flat planting methods) and four subplot zinc levels: absolute control, RDF + 0 kg Zn ha^{-1}, RDF + 10 kg Zn ha^{-1}, and RDF + 20 kg Zn ha^{-1}, replicated thrice. The soil was sandy loam with a pH of 8.16, indicating alkaline conditions. Results showed that bed planting significantly improved tiller count, dry matter accumulation, grain and straw yield, and the availability of nitrogen, phosphorus, potassium, and zinc. Zinc application, particularly RDF + 20 kg Zn ha^{-1}, significantly enhanced plant height, yield parameters, and soil nutrient content, and was statistically at par with RDF + 10 kg Zn ha^{-1}. Test weight, pH, and EC were unaffected by treatments. No significant interaction between land configuration and zinc levels was observed. The study highlights the benefits of integrated zinc nutrition and land configuration in improving soil health and productivity in mint–wheat systems.

Keywords: Soil fertility, Zinc application, Wheat, Mentha.

INTRODUCTION

The menthol-rich essential oil extracted from mint (*Mentha arvensis* L.) has a wide range of industrial uses. Mint species are popular household and natural medicinal herbs that, when distilled, yield essential oil that contains menthol, menthone, menthyl esters, and other compounds. This oil is used as a condiment in toothpaste, sweets, peppermint gum, mouth cleansers, and beverages, as well as an ingredient in pharmaceutical (analgesic, anti-inflammatory, and anti-spasmodic) and cosmetic industries (Verma *et al.*, 2010). 80 to 85 percent of India's mint production comes from Uttar Pradesh, while the remaining 15 to 20 percent comes from Punjab, Bihar, M.P., Haryana, Himachal Pradesh, and other states. It was cultivated on around 13365 ha in Punjab state in 2018–19 (Anonymous, 2021).

Wheat (*Triticum aestivum* L.) is a major cereal crop which belongs to the *Poaceae* family and is one of the oldest domesticated grains. One of the most commonly farmed grain crops, wheat provides 18 per cent of the calories consumed worldwide and is very important for human food security (Erenstein *et al.*, 2022). Wheat (*Triticum aestivum* L.) is the staple food and second most important food crop after rice in the country, which contributes nearly one-third of the total food grain production. It is consumed mostly in the form of bread as "Chapati". Wheat straw is used for feeding cattle. Wheat contains more protein than other cereals and has are relatively high content of niacin and thiamine. The most widely grown is common wheat (*Triticum aestivum* L.). It is one of the most consumed cereal crops in the world, and it is cultivated all over the world. It is commonly known as the "king of cereal" for a significant life span, and it is still holding the pride of place even today. Land configuration increases water use efficiency (Chiroma *et al.*, 2008). Globally, wheat (*Triticum aestivum* L.) is the most important crop grown in an area of 217.8 million hectares (Mha) (Knoema, 2022) with a production of 794.6 million tonnes (MT) (Anonymous, 2022). India is the second leading producer of wheat cultivation in the world with an average annual production of 109.52 MT in the current year (Anonymous, 2022).

After wheat harvesting, there is a 2-3-month fallow period which results in the debility of structural stability leading to the degradation of soil quality through decreasing soil organic C (Mikha *et al.*, 2006). To make the most of the growing season, wheat and some profitable crops such as mentha, celery, summer moong and mash, etc. may be viewed as a system as relay intercropping is a useful method for reducing soil erosion and enhancing soil fertility and quality by ensuring that the resources provided by niche differentiation and complementarity are utilized properly. The viable options are to grow mint after wheat because relay intercropping of wheat and mint is more ruminative than solitary planting of wheat. The border row effect adds to wheat yield restoration because wheat has a relatively great leaf area, which results in the absorption of extra available light by the border row, which boosts various yield-attributing characters of wheat (leaf area index, height, etc.) in relay cropping system (Mao *et al.*, 2014).

Mint species are well-known household and natural medicinal herbs that provide essential oil containing menthol, menthone, menthyl esters, etc. on distillation which is widely utilized as an ingredient in pharmaceutical (analgesic, anti-inflammatory, and anti-spasmodic medicines) and cosmetic industries, as well as a condiment in toothpaste, sweets, peppermint gum, mouth cleansers, and beverages (Kumar *et al.*, 2024). The world's major producers of mentha oil are India, China, Brazil, and the United States. However, India holds a distinct position in mentha oil commerce and export, accounting for over 80% of total global production. It is primarily grown in the states of Uttar Pradesh, Punjab, Haryana, and parts of Tamil Nadu (Aswani *et al.*, 2020). Uttar Pradesh is India's primary mint-producing state, accounting for 80-85% of total production, with the remaining 15-20% coming from Punjab, Bihar, M.P., Haryana, Himachal Pradesh, and other states. During the year 2018-19, it was grown on around 13365 hectares in Punjab state (Anonymous, 2021). As a result, it provides a strong opportunity for the diversification of cereal-based cropping systems.

Wheat is usually cultivated as a flat-planted crop in India, especially in the states of Punjab, Haryana, etc. The flat planting and bed planting method significantly produces a grain yield of about 32.15 q ha^{-1} and 37.36q $ha^{-1,}$ respectively. The reduction in yield in the flat planting method was due to unfavorable field conditions such as waterlogging, insufficient standing power of the crop, etc., which led to crop lodging (Momtazi *et al.*, 2024). Whereas the bed planting method is an important component of the physical environment of the soil and affects crop establishment, growth, and yield by influencing plant roots, soil nutrients, and moisture extraction patterns which in return boosted input usage efficiency of the crop with higher grain yield (Dhillon *et al*., 2004). The bed planting method could prevent waterlogging, control the weeds, and save up to 50% of the water and 20–25% of the yield over the conventional method (Tang *et al*., 2024). Compared to flat sowing, bed planting has been shown to reduce soil penetration resistance and bulk density (Du *et al.*, 2024).

When two or more crops are intercropped, their fertilizer requirements may differ greatly from the sole crop demand, making balanced nutrition more difficult. There has been a lot of research done on the zinc requirements of wheat and mentha as sole crops; however, there is hardly any available information on intercropped systems. As discussed earlier, the regular practices of sowing on flat beds has led to yield losses due to lodging and depletion of important soil nutrients and decreased soil fertility. Therefore, keeping in mind the importance of zinc requirement, intercropping system and two land configurations, the present study "Effect of Zinc Levels on Soil Physico-Chemical Properties in Mint (*Mentha arvensis* L.)–Wheat (*Triticum aestivum* L.) Intercropping System under Two Land Configurations" was undertaken.

MATERIAL AND METHODS

Location and Soil: A field experiment was conducted at Students Research Farm, Khalsa College, Amritsar, Punjab, India during the rabi season of 2021-2022. The experiment was laid out in a split-plot design with two land configurations, *viz.*, Bed and Flat planting methods, as main plot treatments and four zinc levels as subplot treatments, with eight treatment combinations replicated three times. The soil of the experimental plot was low in available nitrogen (186.60 kg ha) and organic carbon (0.40 %), medium in available phosphorus (19.32 kg ha^{-1}) and available potassium (249.82 kg ha^{-1}) as regards to fertility status and alkaline in reaction (pH 8.16). The soil contained diethylene triamine Penta Acetate (DTPA) - extractable n was 0.89 mg kg'. The soil of the experimental field was sandy loam in texture.

Table 1: Soil properties before the start of an experiment.

Sr. No.	Soil properties	Value
1	Particle size distribution	
	Sand (%)	70
	Silt (%)	16
	Clay (%)	14
	Textural class	Sandy loam
2	Bulk density (g cm^{-3})	1.38
3	Particle density (g cm^{-3})	2.60
4	Porosity (%)	47
5	pH	8.16
6	EC(dS m^{-1})	0.29
7	Organic carbon (%)	0.40
Macronutrients		
5	Available N (kg ha^{-1})	186.60
6	Available P (kg ha^{-1})	19.32
7	Available K (kg ha^{-1})	249.82
Micronutrients		
8	Available Zn (mg kg^{-1})	0.89

During the growing season of the crop, the maximum temperature varied from 16.84°C to 45.27°C and the minimum temperature ranged from 5.26°C to 28.39°C. The relative humidity varied from 16.52 to 79.03% during the period of the crop season. The observations were taken at harvest for plant height, number of tillers meter' row length, dry matter accumulation, test weight (g), straw yield (q ha^{-1}, grain yield (q ha^{-1}), pH, EC, and available nutrients (N,P,K and Zn). In order to represent the plot, five plants of wheat from each net plot were selected randomly for various biometric observations on growth and post-harvest studies. The selected five plants were labelled, and all biometric observations were recorded properly on them. Grain and Straw yields were recorded on a plot basis. pH was recorded by a pH meter (Jackson, 1967), EC was estimated by an electrical conductivity meter (Jackson, 1967). The bulk density of soil was determined using the Core method (Prihar and Hundal 1971). The particle density of soil samples from different plots was estimated by using a PAU moisture gauge (Prihar and Sandhu 1968).

Treatments:

Table 2: Detailed Description of Treatments Used in the Field Experiment.

Main Plot Treatments	Treatment Detail
M_1	Bed Planting Method
M_2	Flat Planting Method
Sub Plot Treatments	
T_1	**Control**
T_2	Sole Wheat+ RDF
T_3	Wheat + Mint+ RDF + Zn_0
T_4	Wheat + Mint+ RDF + Zn_1
T_5	Wheat + Mint + RDF + Zn_2

* RDF: Recommended dose of fertilizer; Zn_0: 0 kg $ZnSO_4$ ha^{-1}, Zn_1: 10 kg $ZnSO_4 ha^{-1}$ and Zn_2: 20 kg $ZnSO_4$ ha^{-1}

Cropping Season

Table 3: Detailed Description of the Field Experiment Conducted During the Cropping Season.

Year	Crop season	
	Kharif	***Rabi***
2019-2020	Sorghum	Wheat
2020-2021	Rice	Berseem
2021-2022	Rice	Wheat+Mint (experimental crop)

Statistical analysis. The data generated from the field and laboratories were subjected to statistical analysis of variance techniques. The significance of the treatments on soil properties, nutrient uptake, and crop yield was tested using a split-plot design (at a 5% level of probability).

RESULT AND DISCUSSION

Soil Properties

Bulk density (g cm^{-3}). Different levels of zinc in subplots showed a non-significant effect on the bulk density of soil (Table 4). The highest value of bulk density was found in T_3 (1.37 cm^{-3}). Furthermore, the data in Table 4 indicate that a statistically significant difference in soil bulk density was found between the two land configurations. Numerically, raised bed planting resulted in the lowest bulk density (1.33 g cm^{-3}) as compared to flatbed planting (1.39 g cm^{-3}). The reduction in bulk density under raised beds could be attributed to pores formed in the beds as a result of accumulating surface soil and limiting traffic to the furrow bottoms. The results are similar to the findings of Shah *et al.* (2015); Tang *et al.* (2024).

Particle density (g cm^{-3}). Regarding zinc application in subplots, a non-significant difference was observed in the particle density of the soil. The data in Table 4 revealed that T_4 (0.62) showed numerically higher particle density, followed by T_3 (0.61), and a lower value was observed under control (0.60). Similarly, particle density of soil was affected non-significantly in under underplanting methods. Data in Table 4 shows that the flat planting method (2.61) resulted in numerically higher particle density than the bed planting method (2.60). These findings are in line with Jat *et al.* (2022); Tang *et al.* (2024).

Porosity (%). According to the results in Table 4, an opposite trend to that of bulk density was observed in both subplot and main plot treatments for soil porosity. The maximum value was recorded in T_4 (48.40), and the lowest was recorded in T_3 (47.41) under the subplot treatment. The bed planting method has a higher (48.66) porosity than the flat (46.82) planting method, but it does not differ significantly. Interaction was non-significant. These findings are in line with Jat *et al.* (2022).

Soil pH. The data in Table 4 shows that pH was decreased with the application of zinc in the soil. Numerically, higher pH (8.17) was observed under T_3 treatment, where no Zn was given, followed by T_1 (8.15). Lower pH (8.14) was noticed in T_4 and T_5 plots where Zn was applied, but the difference among all these treatments did not reach to level of significance.

Further, data in Table 4 revealed that raised bed as well as flatbed planting had shown a non-significant effect on soil pH. However, raised beds (8.16) recorded a higher pH than flat beds (8.14). The results were similar to the findings of Kaur *et al.* (2020).

Electrical conductivity (dSm^{-1}). Soil EC under all the treatments was increased numerically in comparison with the control in the order $T_5 > T_4 > T_3 > T_1$, but the EC was found to be non-significant (Table 4). The highest EC value (0.32) was recorded under T_5, where

$ZnSO_4$ @ 20 kg ha^{-1} was applied at the time of sowing of wheat. In the case of the planting method, the bed planting method has a marginally higher value (0.31) than the flat method of planting (0.29). The interaction of zinc and land configuration was found to be non-significant. The results were similar to the findings of Kaur *et al.* (2020).

Organic Carbon (%). The data in Table 4 further revealed that organic carbon was non-significantly affected due to the application of zinc in soil. The highest per cent of organic carbon (0.45) was noticed under T_5 treatment, where $ZnSO_4$ @ 20 kg ha^{-1} was applied, followed by T_4 (0.43) and T_3 (0.43), where $ZnSO_4$ @ 10 kg ha^{-1} and no zinc was given, respectively.

Further, Table 4 shows that under the planting method, the bed planting method recorded a significantly higher (0.45) organic carbon than the flat planting method (0.40). It might be due to carbon addition through the highly proliferating roots in response to decreased bulk density, with an associated increase in total porosity. Hassan *et al.* (2005) also reported the same for raised beds. Sun *et al.* (2024) reported that intercropping increased organic carbon content by 14%.

Table 4: Effect of different levels of Zn on bulk density, particle density, and porosity of soil after harvest of mint (*Mentha arvensis* L.) crop under two land configurations.

Symbols	Treatments	Bulk density (g cm^{-3})	Particle density (g cm^{-3})	Porosity (%)	pH	EC (dSm^{-1})	Organic carbon (%)
	Land configurations						
M_1	Bed planting method	1.33	2.60	48.66	8.16	0.31	0.45
M_2	Flat planting method	1.39	2.61	46.82	8.14	0.29	0.40
$CD_{(p=0.05)}$		0.02	NS	NS	NS	NS	0.04
	Zinc levels						
T_1	Control (Wheat+ Mint)	1.36	2.60	47.58	8.15	0.29	0.41
T_2	Sole wheat + RDF	—	—	—	—	—	—
T_3	Wheat + Mint + RDF+ Zn_0	1.37	2.61	47.41	8.17	0.30	0.43
T_4	Wheat + Mint + RDF+ Zn_1	1.35	2.62	48.40	8.14	0.31	0.43
T_5	Wheat + Mint + RDF+ Zn_2	1.36	2.60	47.59	8.14	0.32	0.45
$CD_{(p=0.05)}$		NS	NS	NS	NS	NS	NS
Interaction		NS	NS	NS	NS	NS	NS

* RDF: Recommended dose of fertilizer; Zn_0: 0 kg Zn ha^{-1}, Zn_1: 10 kg Zn ha^{-1}, Zn_2: 20 kg Zn ha^{-1}

Effect of different levels of Zn on growth and yield parameters of mint (*Mentha arvensis* L.) crop under two land configurations.

Plant height (cm). At harvest, the plant height of mint ranged from 48.90 cm (control) to 53.76 cm (T_5). The maximum plant height at harvest was observed in treatment receiving RDF + $ZnSO_4$ @20 kg ha^{-1} (53.76 cm), which was found to be at par with T_4 (53.07 cm), followed by T_3 (50.50 cm), while the lowest was observed in the control (48.90 cm). The increase in plant height with the application of zinc might be due to its involvement in the synthesis of tryptophan- a precursor of IAA (Indole-3-Acetic Acid) - which acts as a growth-promoting substance. While observing the effect of planting methods on the plant height of mint crops, the perusal of data presented in the Table 5 showed that the higher plant height of wheat was recorded under the bed planting method as compared to the flat planting method but they differed non-significantly did not vary from one another (Kaur *et al.*, 2013).

Leaf area index (LAI). The maximum LAI recorded was 3.36 and 4.93 in T_5, while the minimum LAI was registered as 3.14 and 4.67 in control (T_1) at harvest, respectively. This might be due to zinc-induced improvement in photosynthetic activities and biosynthesis of auxin, which plays a cardinal role in the coordination of many growth processes in the plant life cycle and ultimately increases in leaf area index. Raised bed recorded significantly higher leaf area index (3.29 and 4.84) than flatbed planting (3.25 and 4.80). A better and more developed root system in the loose, fertile soil of beds might have improved water availability and nutrient uptake, resulting in a maximum leaf area index.

Data furnished in Table 5 indicated that the leaf area index in mint was influenced significantly by land configuration at all growth stages of the crop except 60 DAP. Raised bed recorded significantly higher leaf area index (3.29 and 4.84) than flatbed planting (3.25 and 4.80). A better and more developed root system in the loose, fertile soil of beds might have improved water availability and nutrient uptake, resulting in a maximum leaf area index. Results are similar to the findings of Gul *et al.* (2015).

Oil content (%). An examination of data revealed that the zinc sulfate @ 20 kg ha^{-1} (T_5) recorded the highest oil content (0.82 %) over the control (0.64 %), and T_5 was found to be at par with T_4 (0.80%). The pronounced effect of zinc application on different growth patterns like plant height, leaf area, dry matter accumulation, and yield components, including fresh and dry herbage yield, relates to the respective varying trends of different quality attributes. The planting method had a non-significant effect on oil content (%), having marginally higher content (0.76 %) when the crop was grown on the raised bed method of planting (M_1) than the flat method of planting (0.74 %). Zinc plays a crucial role in the activation of enzymes involved in terpenoid biosynthesis, a key pathway for essential oil production in mint. It also enhances chlorophyll synthesis and photosynthetic activity, thereby promoting greater biomass and essential oil accumulation (Mehdizadeh *et al.*, 2024). The results are similar to the findings of Kaur *et al.* (2013).

Table 5: Effect of different levels of Zn on Leaf area index (LAI), plant height, oil content (%), and oil yield (kg ha^{-1}) of mint (*Mentha arvensis* L.) crop under two land configurations.

Symbols	Treatments	Leaf area index (LAI)	Plant height (cm)	Oil content (%)	Oil yield (Kg ha^{-1})
	Land configurations	**At harvest**	**At harvest**		
M_1	Bed planting method	4.84	52.53	0.76	102.66
M_2	Flat planting method	4.80	50.58	0.74	93.70
	$CD_{(p=0.05)}$	0.01	NS	NS	3.37
	Zinc levels				
T_1	Control	4.67	48.90	0.64	77.17
T_2	Sole wheat + RDF	—	—	—	—
T_3	Wheat + Mint + RDF+ Zn_0	4.80	50.50	0.75	95.65
T_4	Wheat + Mint + RDF+ Zn_1	4.91	53.07	0.80	108.36
T_5	Wheat + Mint + RDF+ Zn_2	4.93	53.76	0.82	111.55
	$CD_{(p=0.05)}$	0.09	1.39	0.03	3.35
	Interaction	NS	NS	NS	NS

*RDF: Recommended dose of fertilizer; Zn_0: 0 kg Zn ha^{-1}, Zn_1: 10 kg Zn ha^{-1}, Zn_2: 20 kg Zn ha^{-1}

Oil yield (kg ha^{-1}). Data about oil yield (kg ha^{-1}) as influenced by residual zinc and land configuration are presented in Table 3. The data revealed that zinc sulphate applied @ 20 kg ha^{-1} (T_5) recorded the highest oil yield (111.55 kg ha^{-1}) over the control (77.17 kg ha^{-1}), and T_5 was found to be at par with T_4 (108.36 kg ha^{-1}). The enhancement in yield attributes under T_5 might have increased the concentration of photosynthates and secondary metabolites in herbage, which further accounted for the higher essential oil yield under the respective treatments.

The planting method had a significant effect on oil yield per hectare, having a maximum yield (102.66 kg ha^{-1}) when the crop was grown on the raised bed method of planting, as compared to the flat method (93.70 kg ha^{-1}). The increase in oil yield in raised bed might be due to an increase in leaf area index which resulted in the production of more photosynthates resulting in better plant growth in terms of plant height, spread, and branches that increases the herb yield and ultimately oil yield of mint (Kumar *et al.*, 2020). Interaction was non-significant.

CONCLUSIONS

The raised bed planting system performed better than other sowing techniques in terms of wheat and mint growth, yield, and quality. Furthermore, given that mint is not harmful to wheat performance, continuously intercropping it with wheat is an improved method to increase growth, yield, and oil.

FUTURE SCOPE

The present study underscores the potential of zinc fertilization and land configuration in improving soil health and productivity in a mint (*Mentha arvensis* L.)–wheat (*Triticum aestivum* L.) intercropping system. Future research should focus on long-term and multi-location trials to validate these findings under diverse conditions. Economic analysis would help determine the cost-effectiveness for farmers. Additionally, exploring the impact of zinc on soil microbial health and evaluating alternative sources like nano- or slow-release zinc formulations could enhance nutrient efficiency. Assessing crop quality traits and examining the role of these practices in improving resilience to abiotic stress, such as drought or salinity would further strengthen their relevance under changing climate scenarios.

Conflict of Interest. None.

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