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The influence of primary soil tillage methods and foliar nutrient provision on the growth, yield, and associated traits of winter barley (*Hordeum vulgare* L.)

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SUMMARY

Sustainable agricultural practices are vital for ensuring global food security. Factors such as soil, weather, and agronomic practices, including nutrient supply and tillage systems, play key roles in sustainable crop production. A field experiment at the Hungarian University of Agriculture and Life Sciences in Godollo, Hungary, assessed the impact of primary soil tillage methods and foliar nutrient supplementation on winter barley yield and traits. Using a split-plot design with three replications, the study examined four nutrient treatment (control, Bio-cereal, bio-algae, and MgSMnZn Blend) and two tillage methods (plowing and cultivator). The obtained results indicated no significant influence of tillage treatments on SPAD value, leaf area index (LAI), plant height, or spike length. However, nutrient treatments significantly ($P<0.01$) affected LAI, plant height, and thousand kernel weights. Both nutrient and tillage treatments significantly ($P<0.01$ and $P<0.05$) influenced tiller number and grain yield, with significant ($P<0.01$) interaction effects observed for grain yield and kernel weight. The combination of Bio-cereal nutrient treatment with plowing tillage produced the highest values across parameters. Thus, integrating bio-cereal nutrient supplementation with plowing tillage is better for optimizing winter barley yield.

Keywords: *bio-algae; bio-cereal; cultivator; plowing*

INTRODUCTION

Barley (*Hordeum vulgare* L.), the fourth-largest cereal crop globally (FAO, 2023), has played a critical role in human diets for thousands of years (d'Alpoim et al., 2016). Its widespread appeal stems from its adaptability to diverse environmental conditions, enabling farmers to achieve economically viable yields (Caproni et al., 2023; Wang et al., 2018). Barley demonstrates remarkable resilience, thriving in main and short rainy seasons and areas with residual soil moisture (Grando and Macpherson, 2005). Beyond its role in food security, barley is a key component in beer production and animal feed. Nutritionally, barley grains are a rich source of dietary fiber, particularly β-glucan and tocols, which provide various health benefits, such as reducing the risk of circulatory diseases, hypertension, and diabetes (Shu and Rasmussen, 2014). This nutritional profile, along with its functional food potential, has earned barley recognition for its significant health benefits (Geng et al., 2022).

The projected global population increase of two billion by 2050, coupled with the risk of hunger and malnutrition affecting one billion people, underscores the urgency of improving food security (Rosegrant et al., 2014; Musker and Schaap, 2018). Addressing this challenge requires a sustained increase in cereal production and yield stability to meet rising grain demand. Sustainable agricultural practices, particularly for winter barley, are essential in this context (Musker and Schaap, 2018). Achieving optimal barley yields depends on multiple factors, including nutrient availability, varietal differences, climatic conditions, and soil tillage practices (Darby et al., 2011). Effective management of nutrient supply, appropriate tillage systems, pest and disease control, and drought mitigation are critical for overcoming these constraints.

Focusing on soil tillage and nutrient management is vital to enhancing winter barley productivity and quality (Vakali et al., 2015). As a crucial natural resource, the soil supports plant growth, and its effective management is key to achieving desired crop yields (Gupta, 2019). Implementing appropriate tillage practices can influence soil-mediated processes, including carbon sequestration, water quality, and greenhouse gas emissions such as CO_2, CH_4, and N_2O (Alam and Salahin, 2013; Bhattacharyya et al., 2022). Sustainable tillage practices help address climatic and soil challenges while supporting ecosystem services. Integrating precision agriculture technologies and sustainable agronomic strategies is essential to improving productivity while minimizing environmental impacts.

Depleting soil fertility, due to insufficient fertilizer use, continuous nutrient extraction by crops, and limited organic matter application, highlights the need for effective nutrient management practices (Dhiman and Dubey, 2017; Kidane, 2015). These strategies aim to optimize crop management, enhance genetic potential, and reduce greenhouse gas emissions, emphasizing the importance of sustainable practices (Balafoutis et al., 2017). Hence, this study investigates the relationship between soil tillage methods, foliar nutrient supplementation, and their combined effects on winter barley yield and related traits, providing insights for sustainable agricultural advancements.

MATERIALS AND METHODS

Description of experimental site

The field experiment was carried out during the winter cropping season of 2022/2023 at the experimental plot of the Department of Agronomy, part of the Hungarian University of Agriculture and Life

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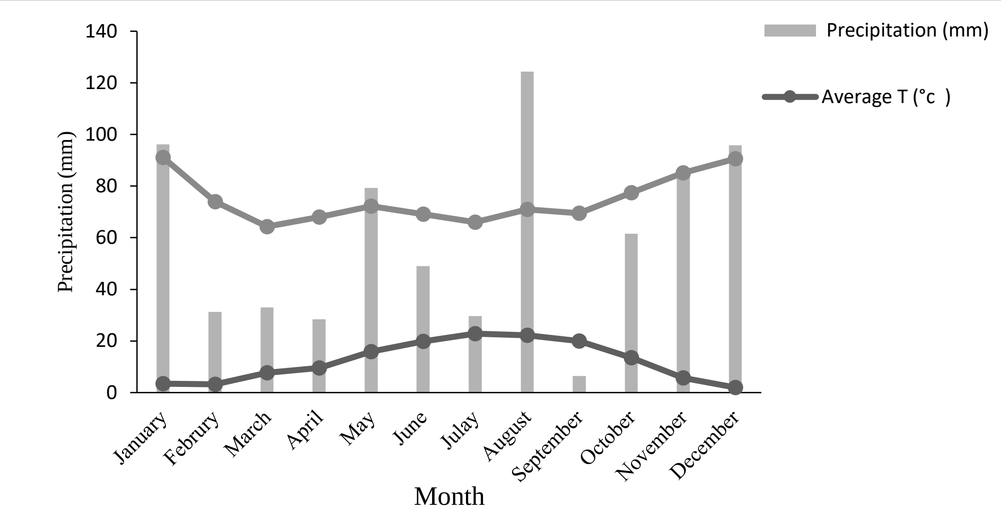
Sciences, situated in Godollo, northeast of Budapest, Hungary. The site is geographically positioned at approximately 47° 36′ 0″ N latitude and 19° 22′ 0.12″ E longitude, with an elevation of 207 meters (690 feet) above sea level. The soil at the location is characterized as sandy loam. During the experimental period, data on average temperature, precipitation, and relative humidity were monitored and recorded (*Figure 1*).

Figure 1. **Meteorological data recorded during the 2023 cropping season at the experimental site**



Treatments, experimental design and procedure

The field experiment had a split-plot design within a randomized complete block arrangement, with three replications to ensure reliable results. Each sub-plot measured 5 m × 6.2 m, covering an area of 31 m². A 1-meter spacing was maintained between sub-plots, while blocks were separated by 2 meters to ensure uniformity. The study included two primary factors: primary soil tillage methods (Plowing with the depth of 30 cm and Cultivator with the depth of 28 cm) and foliar nutrient treatments [Control, Fitohorm Bio-cereal (5 L ha^{-1}), Bio Algae (30 L ha^{-1}), and MgSMnZn Blend (4.301 L ha^{-1})]. Tillage treatments were applied to main plots, while nutrient treatments were assigned to sub-plots. Land preparation was conducted using tractor-facilitated tillage methods, and the crop was received baseline fertilization such as phosphorus (111.1 mg kg^{-1}) and potassium (119.9 mg kg^{-1}) from the soil before sowing. Winter barley seeds (KH TARNA variety) were planted at a seeding rate of 190 kg ha^{-1} with 12 cm row spacing in the beginning of October. Weeds were managed using granstar super 50 SX herbicideswith the recommended dose of 50 g ha^{-1} to create a favorable growth environment, and the crop was harvested at physiological maturity in the mid of July.

Data collection and measurements

Chlorophyll content (SPAD values) was measured weekly using a handheld SPAD meter (SPAD-502Plus, Konica Minolta, Tokyo, Japan). Readings were taken from 10 fully expanded, intact leaves per plot to ensure consistency across treatments.

Leaf Area Index (LAI) was also assessed weekly using a PAR LP-80 ceptometer (METER Group, Inc. USA), which measured above- and below-canopy PAR. LAI values were automatically calculated based on light interception, following established methodologies (Hay and Walker, 1989; Cooper, 1976). Growth parameters, including plant height and spike length, were evaluated at physiological maturity. Measurements were taken from 10 randomly selected plants per plot, with plant height recorded from the base to the tip of the spike (excluding crowns) and spike length also noted to provide a comprehensive overview of plant development. Effective tiller number were assessed by counting productive tillers on 10 individual plants per plot. Grain yield was measured by harvesting a defined area of 6.25 m² per plot, with weights adjusted to account for a moisture content of 12.5%. Additionally, thousand kernel weight (TKW) was determined using a sensitive balance, and grain yields were standardized and expressed in tons per hectare (t ha^{-1}) to facilitate comparison across different treatments.

Statistical data analysis

Data analysis was conducted using IBM SPSS version 29. The normality of the data was confirmed through the Shapiro–Wilk test (Shapiro and Wilk, 1965) and skewness and kurtosis evaluations (Kim, 2013). Levene's test was employed to check variance homogeneity. Multivariate analysis of variance (MANOVA) was applied to assess treatment effects, with Bonferroni correction used to evaluate parameter significance. Tukey's test ($p<0.05$) was employed for mean comparisons. Visual data representations were prepared in Microsoft Excel, and Pearson correlation analysis was conducted to explore relationships among variables, offering additional insights into the experimental findings.

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RESULTS AND DISCUSSION

Effect of foliar nutrient and primary tillage methods on leaf chlorophyll content

The results of the multivariate analysis of variance (MANOVA) revealed that there were no significant differences observed among the main effects of nutrient treatments and between the different tillage treatments concerning leaf chlorophyll content. Similarly, the interaction effects of nutrient treatment and soil tillage treatment was not show significant difference (*Table 1*).

Effect of foliar nutrient and primary tillage methods on leaf area index (LAI)

The MANOVA analysis revealed a statistically significant disparity in leaf area index attributable to the main effect of nutrient treatments (P<0.05). However, no statistically significant differences (p>0.05) were discerned between soil tillage treatment and the interaction of nutrient and soil tillage treatment (*Table 1*). In *Table 2*, mean values indicated the application of the bio-cereal nutrient treatment resulted in the highest recorded leaf area index, reaching a value of 2.440. Notably, the remaining three (i.e., control, bio alga and MgSMnZn Blend) treatments exhibited comparable statistical significance values.

The leaf area index is a plant photosynthetic capacity indicator (Majeed, 2020) that has been connected to changes in canopy structure, altering light interception and, ultimately, plant photosynthesis and yield (Bi & Zhou, 2021). According to Matsuda et al. (2011), there is a link between leaf area index (LAI) and light interception, suggesting that differences in LAI can influence the amount of light plants are able to absorb. However, nutrient management and related strategies have been shown to have an impact on the LAI. Our study revealed that applying bio-cereal nutrient during the stem elongation phase enhances the leaf area index (LAI) of winter barley. This enhancement can be attributed to the unique formulation of the fertilizer, which contains a combination of essential micronutrients (Fe, Mn, Cu, Zn, B, Mo) that meet the crop's seasonal nutrient demands. The inclusion of these micronutrients appears to significantly influence plant growth dynamics. Previous research has also documented notable improvements in plant growth parameters following nutrient application (Akram et al., 2022). Importantly, the extent to which nutrient application impacts LAI is influenced by the nutrient source, emphasizing the critical role of nutrient management in plant development (Garg et al., 2020). It has been further established that targeted nutrient application can lead to measurable differences in LAI (Zahra et al., 2024; Adnan et al., 2020), reinforcing the importance of effective nutrient management in optimizing crop growth.

Table 1. **Multivariate analysis of variance (MANOVA) for SPAD value, leaf area index, Plant height(cm) Spike length (cm), effective tiller number, grain yield (t ha^{-1}) and thousand kernel weights (g) of winter barley in different foliar nutrient type and primary tillage type**

Dependent variables	Source of Variations											
	Tillage treatment				Nutrient treatment				Tillage *Nutrient			
	Df	Mean Square	F-value	Sig.	Df	Mean Square	F-value	Sig.	Df	Mean Square	F-value	Sig.
SPAD Value	1	75.713	1.906	0.169	3	63.866	1.608	0.188	3	63.321	1.594	0.192
Leaf Area Index	1	1.004	2.334	0.128	3	2.098	4.879	0.003	3	1.344	3.126	0.270
Plant Height (cm)	1	201.667	3.819	0.520	3	320.619	6.072	<0.001	3	133.342	2.525	0.58
Spike Length (cm)	1	4.167E-5	0.000	0.995	3	0.282	0.244	0.865	3	0.129	0.112	0.953
Effective tiller number	1	41.667	33.356	<0.001	3	12.317	9.860	<0.001	3	4.656	3.727	0.108
Grain Yield (t ha^{-1})	1	10.617	8.191	0.041	3	8.711	6.720	<0.001	3	9.353	7.215	<0.001
TKW (g)	1	31.320	5.871	0.145	3	281.727	52.80	<0.001	3	75.567	14.165	<0.001

Table 2. **The mean value of leaf chlorophyl content (SPAD), leaf area index (LAI), plant height (cm) and spike length (cm) of winter barley by different nutrient and primary soil tillage treatment**

Nutrient treatment	Studied Parameters			
	Leaf chlorophyll (SPAD value)	Leaf area index (LAI)	Plant height (cm)	Spike length (cm)
Control	39.930± 6.672^{a}	2.105± 0.615^{a}	77.358±7.073^{a}	7.408 ± 1.155^{a}
Bio-cereal	42.127± 5.964^{a}	2.440± 0.659^{b}	82.733±6.722^{b}	7.433 ± 0.985^{a}
Bio alga	40.697± 6.052^{a}	2.283 ± 0.765^{a}	79.725± 8.077^{a}	7.552 ± 0.947^{a}
MgSMnZn Blend	39.947 ± 6.634^{a}	2.022 ± 0.614^{a}	78.517±7.576^{a}	7.408 ± 1.155^{a}
Tillage type				
Plowing	41.237± 6.221^{a}	2.277 ± 0.545^{a}	80.500 ± 6.237^{a}	7.450 ± 0.986^{a}
Cultivator	40.113 ± 6.477^{a}	2.148 ± 0.792^{a}	78.666 ± 8.688^{a}	7.451 ± 1.133^{a}

Different letters indicate a significant difference between treatments at p < 0.05, ±, standard deviation

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Effect of primary tillage methods and foliar nutrient supply on the growth parameters of winter barley

The Multivariate Analysis of Variance (MANOVA) in this study identified a significant difference in plant height ($p<0.05$) driven by the main effect of nutrient treatment. However, no statistically significant differences were observed for tillage treatments or their interactions (*Table 1*). Similar to the trend seen in the leaf area index, the bio-cereal nutrient treatment recorded the highest average plant height of 82.733 cm (*Table 2*), reflecting a 6.94% increase compared to the control. Other fertilizer treatments showed no notable difference from the control, suggesting that the bio-cereal nutrient is particularly effective in enhancing plant height in winter barley. These findings shed light on the complex relationship between agronomic practices and plant morphology, offering valuable insights for improving agricultural productivity and resource management. Consistent with prior research (Surányi and Izsáki, 2016), the study underscores the critical role of specific nutrient applications in promoting winter barley growth. However, no significant differences ($p>0.05$) were observed in spike length across different nutrient treatments, tillage methods, or their interactions (*Table 1*).

Effect of primary tillage methods and foliar nutrient supply on yield and related traits of winter barley

The MANOVA analysis revealed significant variations in tiller number, thousand-kernel weight, and grain yield, driven by the main effects of tillage and nutrient treatments, as well as their interactions. Regarding tiller number, both tillage and nutrient treatments showed significant differences ($p<0.05$) (*Table 1*), while their interaction was not significant. According to *Table 3*, the highest tiller numbers were recorded with bio-cereal (6.55) and bio-algae (6.40) treatments, whereas the lowest were observed in the control (5.8) and MgSMnZn Blend (5.61). Among tillage methods, plowing had the highest tiller number (6.508), outperforming cultivator tillage.

For thousand-kernel weight, significant differences were noted for nutrient treatments and their interaction with soil tillage (*Table 1*), though no significant difference was observed for tillage treatments alone. Mean values in *Table 3* showed the bio-cereal treatment achieved the highest weight (44.238 g), followed by bio-algae (40.615 g) and MgSMnZn Blend (40.588 g), with the lowest recorded in the control (39.163 g). These findings suggest that bio-cereal and bio-algae treatments significantly enhance both tiller number and thousand-grain weight, likely due to their composition of multiple nutrients and the modern chelating agent in bio-cereal, which enables efficient nutrient uptake. Previous studies (Kadhim et al., 2019) have demonstrated similar benefits of algae extracts and bio-fertilizers in improving growth parameters, while others (Liu et al., 2020; Moitazedi et al., 2023) have shown the positive effects of micronutrients on grain filling and kernel weight in maize and wheat.

The association of higher tiller numbers with plowing may be attributed to the deeper soil disturbance, which enhances root density and access to water and nutrients (Guan et al., 2014; Moraes et al., 2019). This process likely promotes tiller initiation and development. Plowing is also more effective than cultivator tillage at incorporating crop residues, improving soil fertility, and facilitating nutrient availability (Wasaya et al., 2019). This aligns with findings (Leghari et al., 2015) showing conventional tillage improves growth, yield, and yield-related traits compared to reduced or no-tillage methods.

Grain yield, reflecting overall crop performance, exhibited significant differences for tillage and nutrient treatments ($p<0.05$), as well as their interactions (*Table 1*). *Table 3* highlights bio-cereal as the top performer (4.209 t ha^{-1}), followed by bio-algae (3.902 t ha^{-1}), with the control (3.476 t ha^{-1}) and MgSMnZn Blend (3.395 t ha^{-1}) yielding the least. Plowing also outperformed cultivator tillage, producing 11.89% higher yield (3.956 t ha^{-1}). Bio-cereal increased grain yield by 21% compared to the control and by 7.85% and 23.99% compared to bio-algae and MgSMnZn Blend treatments, respectively. These findings underline the value of targeted nutrient strategies in enhancing productivity, particularly with bio-cereal treatments. The results align with studies (Yan et al., 2022; Šíp et al., 2013) showing tillage and nutrient application influence yield but contradict findings (Paré et al., 2015) that reported inconsistent effects of tillage on crop yields. These insights provide practical guidance for improving winter barley production through effective resource management.

Table 3. **The mean value of tiller number, thousand kernel weight (g) and grin yield (t ha^{-1}) of winter barley by different foliar nutrient and primary tillage treatment**

Nutrient treatment	Studied Parameters		
	Effective tiller Number per plant	Thousand kernels Weight (g)	Grain Yield (t ha^{-1})
Control	5.800 ± 0.766^{a}	39.163 ± 2.248^{a}	3.476 ± 0.794^{a}
Fitohorm Bio-cereal	6.550 ± 1.285^{b}	44.238 ± 2.152^{b}	4.209 ± 1.379^{b}
Bio alga	6.400 ± 1.509^{b}	40.615 ± 3.077^{c}	3.902 ± 1.603^{a}
MgSMnZn Blend	5.617 ± 1.158^{a}	40.588 ±2.489^{c}	3.395 ± 0.807^{a}
Tillage type			
Plowing	6.508 ± 0.828^{a}	40.790 ± 2.649^{a}	3.956 ± 0.593^{a}
Cultivator	5.675 ± 1.475^{b}	41.512 ± 3.520^{a}	3.535 ± 1.622^{b}

Different letters indicate a significant difference between treatments at $p < 0.05$, ±, standard deviation

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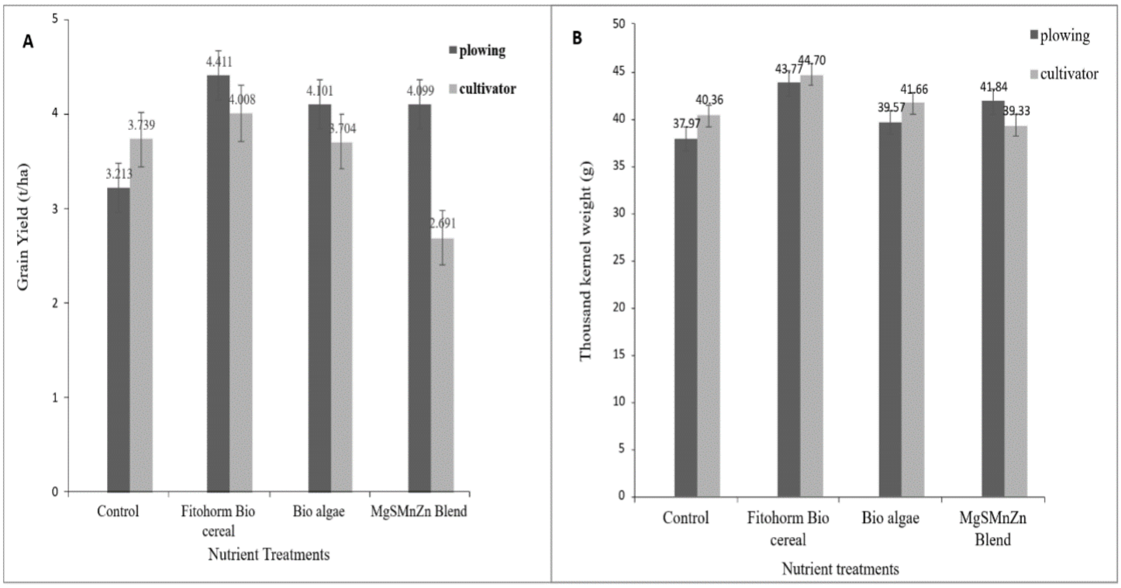
Interaction effect of foliar nutrient and primary tillage methods on grain yield and thousand kernel weight of winter barley

Figure 2 presents the interaction effects of nutrient and tillage treatments on grain yield and thousand-kernel weight. The analysis revealed that the highest grain yield, 4.41 t ha^{-1}, was achieved by combining the bio-cereal nutrient treatment with plowing tillage. This was followed by a grain yield of 4.101 t ha^{-1} obtained from the combination of bio-algae nutrient treatment and plowing tillage. On the other hand, the lowest grain yield, 2.691 t ha^{-1}, was recorded when the MgSMnZn Blend nutrient treatment was used with cultivator tillage. Additionally, the combination of the control treatment with plowing tillage produced a grain yield of 3.213 t ha^{-1}.

Regarding thousand-kernel weight, the interaction of bio-cereal nutrient treatment with both cultivator and plowing tillage resulted in the highest values, 44.7 g and 43.77 g, respectively. In contrast, the lowest values were recorded for the control treatment with plowing tillage (37.97 g) and the MgSMnZn Blend nutrient treatment with cultivator tillage (39.33 g). The combination of bio-algae nutrient treatment with cultivator tillage yielded a thousand-kernel weight of 41.66 g, while the interaction of micronutrient treatment with plowing tillage produced a slightly higher value of 41.84 g. These findings suggest that nutrient management, particularly the use of bio-cereal and bio-algae nutrient treatments, plays a pivotal role in enhancing both grain yield and thousand-kernel weight. The superior performance of bio-cereal nutrient treatment, especially when combined with plowing tillage, indicates its effectiveness in promoting optimal crop growth and development. This finding may be attributed to the nutrient composition of the bio-cereal treatment, which likely facilitates efficient nutrient uptake and utilization by the plants. Furthermore, the results highlight the significant influence of tillage methods, with plowing providing better outcomes for grain yield and kernel weight compared to cultivator tillage. The deeper soil disturbance and improved nutrient availability associated with plowing likely contribute to these positive results.

Figure 2. (**A) Interaction effects of nutrient and soil tillage on grain yield (t ha^{-1}) of winter barley, (B) Interaction effects of nutrient and soil tillage on thousand kernel weights (g) of winter barley**



Correlation between growth parameters, yield and yield related traits

Correlation analysis provides valuable insights into the interrelationships among essential crop traits, aiding in the development of a guiding model to enhance grain yield, either directly or indirectly (Khan et al., 2004). Correlation analysis among growth parameters, yield, and yield-related traits, as presented in *Table 4*, reveals several significant relationships. SPAD (Single Photon Avalanche Diode) values exhibit statistically significant positive correlations with Tiller number (0.345**), Yield (0.336**), and TKW (Thousand Kernel Weight) (0.265**). Conversely, SPAD values display a weak negative correlation with Spike Length (-0.017), suggesting a marginal decrease as spike length increases, although this correlation lacks statistical significance. Additionally, LAI demonstrates significant positive associations with Tiller number (0.563**), Yield (0.581**), and TKW (0.509**). Furthermore, Plant height is positively correlated with LAI (0.475**), Spike Length (0.394**), Tiller number (0.506**), and yield (0.563**). Despite Spike Length showing non-significant positive correlations with LAI (0.083), it displays a significant positive correlation with Plant Height (0.394**). Notably, Tiller number exhibits significant positive correlations with SPAD (0.345**), LAI (0.563**), Plant Height (0.506**), Yield

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(0.780**), and TKW (0.472**). Additionally, Yield demonstrates a strong positive correlation with LAI (0.581**), Tiller number (0.780**), and TKW (0.742**). Likewise, TKW shows significant positive correlations with LAI (0.509**), plant height (0.508**), Tiller number (0.472**), and Yield (0.742**). This correlation result suggests that higher values of these traits are associated with increased grain yield. These findings underscore the importance of these physiological and yield trait characteristics in predicting and potentially enhancing grain yield in the studied crop. Several studies have reported similar results. For instance, grain yield showed strong positive correlations with yield component traits in barley (Dyulgerova, 2012; Bogale et al., 2021). Similarly, significant positive correlations were found between grain yield and various yield-related parameters, such as spike density, productive tillers per plant, grain weight per plant, number of grains per spike, grain weight per spike, and thousand grain weight (Markova et al., 2015). Moreover, similar results have been reported by different researchers (Mirosavljević et al., 2015; Dogan et al., 2016; Ayer et al., 2017).

Table 4. **The relationship between growth, yield and yield related parameters of winter barley**

	SPAD	LAI	PH (cm)	SL	TN	Yield (t ha^{-1})	TKW (gram)
SPAD	1						
LAI	.159*	1					
Plant height (cm)	.144*	.475**	1				
Spike Length (cm)	-.017	.083	.394**	1			
Tiller number	.345**	.563**	.506**	.004^{ns}	1		
Yield (t ha^{-1})	.336**	.581**	.563**	.039^{ns}	.780**	1	
TKW (gram)	.265**	.509**	.508**	.017^{ns}	.472**	.742**	1

SPAD= Single Photon Avalanche Diode, LAI=Leaf Area Index, PH=Plant Height, SL=spike Length, TN= Tiller Number, TKW= Thousand kernel weight

CONCLUSIONS

This study demonstrated that nutrient and tillage treatments play critical roles in influencing key agronomic traits and grain yield of winter barley. While tillage treatments had no significant effect on SPAD values, leaf area index (LAI), plant height, or spike length, nutrient treatments significantly improved LAI, plant height, and thousand-kernel weight ($P<0.01$). Both nutrient and tillage treatments had significant impacts on tiller number and grain yield ($P<0.01$ and $P<0.05$, respectively), with notable interaction effects ($P<0.01$) observed for grain yield and kernel weight.

Of the examined treatments, the combination of Bio-cereal nutrient supplementation and plowing tillage consistently produced the highest values for grain yield and related traits, underscoring the synergistic effect of these management practices. The superior performance of bio-cereal nutrient treatment highlights its potential to optimize nutrient uptake and promote plant growth, while plowing tillage likely enhances soil fertility and resource availability by facilitating deeper soil penetration and nutrient incorporation.

These findings provide robust evidence supporting the integration of Bio-cereal nutrient treatment with plowing tillage as a strategic approach to maximize winter barley productivity. Adopting this combination offers a sustainable pathway for improving yield-related traits and enhancing overall crop performance, which is vital for addressing global food security challenges and promoting efficient resource utilization in agricultural systems. Future studies could further explore the long-term implications of these practices under varying environmental conditions to ensure broader applicability and sustainability.

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