



EFFECTS OF SOIL COMPACTION ON WHEAT GROWTH, NUTRIENT STATUS, AND ARBUSCULAR MYCORRHIZAL

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Abstract

Soil compaction can alter soil physical conditions, nutrient availability, crop performance, and plant-microbial interactions, yet wheat varieties may differ in their responses to these constraints. This study evaluated the effects of soil compaction on soil properties, wheat growth, nutrient status, and arbuscular mycorrhizal fungal (AMF) symbiosis across five spring-wheat varieties. A balanced 2 x 5 factorial design comprising compacted and non-compacted soil conditions, five wheat varieties, and four replicates per treatment-variety combination was analyzed. Soil physicochemical properties, shoot biomass, grain yield, shoot phosphorus (P) and nitrogen (N), AMF root colonization, fungal lipid biomarkers, and AMF diversity were assessed. Compaction significantly increased soil bulk density and nitrate concentration. Shoot biomass and grain yield did not differ significantly between treatments, whereas shoot P and N concentrations were significantly greater under compacted conditions. Overall AMF colonization, PLFA and NLFA biomarkers, virtual-taxon richness, Shannon diversity, and Simpson diversity were not significantly affected by compaction. However, cultivar-specific responses were evident, with Alderon showing a pronounced increase in AMF root colonization under compacted conditions. Variety significantly influenced grain yield and shoot nutrient concentrations. These findings demonstrate that soil compaction influences wheat primarily through changes in soil physical conditions and nutrient status, while AMF responses depend partly on wheat genotype.

Keywords: Soil compaction; Spring wheat; Arbuscular mycorrhizal fungi; Nutrient status; Grain yield



1. Introduction

In intensive agricultural production systems, repeated machinery traffic, tillage practices and field operations can cause compaction, which is a significant form of physical degradation as it can lead to higher bulk density and reduced pore space for water, air and root growth. All these changes can affect root depth and soil-plant interactions, thereby affecting crop establishment and yield (Shaheb et al., 2021). The most recent evaluations focus on how compaction impacts a variety of soil functions such as aeration, hydraulic conductivity, nutrient transport, microbial activity, and access to soil resources by roots (Frene et al., 2024). In addition, the interactions between roots, fungi, and mechanical traffic also influence soil structure, meaning that biological and physical factors need to be taken into account when examining the compaction effects (Negi et al., 2025).

Wheat (*Triticum aestivum* L.) is especially relevant to this problem because it is very important for wheat to be able to tap into water and mineral nutrients throughout the soil profile. This can therefore affect nutrient uptake and crop growth, even when only minor reductions in aboveground biomass or yield are observed, due to soil physical constraints. Other soil stressors can also be moderated by the presence of arbuscular mycorrhizal fungi (AMF) which form a symbiotic association with the roots and extend the zone of effective nutrient acquisition by extraradical hyphae (Thangavel et al., 2022). In addition to the effects on soil fertility discussed above, AMF can affect aggregation, nutrient cycling, soil biological activity and soil structural stability (Fall et al., 2022).

The role of AM symbiosis is of functional relevance in times of environmental and edaphic stress. Mycorrhizal associations can significantly contribute to plant growth and adaptation by helping to access resources and influencing plant responses to adverse conditions (Mitra et al., 2021). They are gaining importance as a contribution to sustainable agroecosystems as AMF can also work towards nutrient-use efficiency and help reduce reliance on intensive external inputs (Chaudhary et al., 2025). In recent synthesis, several biological pathways are suggested for the influence of AMF on nutrient uptake mechanisms, plant-growth promotion, and crop resilience, which interact with each other (Bhupenchandra et al., 2025). They also play a role in soil health and carbon related processes, thus offering a wider ecological basis to integrate mycorrhizal functioning in sustainable crop management (Shukla et al., 2025).

The use of beneficial soil organisms to create soil health for improved nutrient availability and plant growth under suboptimal conditions is also emphasised in microbial methods (Wei et al., 2024). The relative importance of roots and symbiotic fungi in acquiring nitrogen varies with management conditions in wheat systems, indicating that nutrient uptake is not a function of the root's activity alone, but of root traits and fungal association (Kan et al., 2023). Additionally, AM fungi have been linked to changes in water use and yield formation under water-limited wheat production in the presence of plant-growth-promoting microorganisms (Rehman et al., 2022). The fact that AMF responses are affected by soil physical management practices, as noted in tillage-related changes in wheat root colonization, further suggests the importance of considering soil physical management for AMF responses and its potential relationship with grain production (Taibi et al., 2021).

Furthermore, wheat cultivars can differ in their response to compaction and/or mycorrhizal colonization. Based on spring wheat data, the impacts of soil compaction on AM symbiosis can be highly dependent on host variety and root traits, especially in terms of P acquisition (Torppa et al., 2023). The present study was thus targeted to determine the effect of soil compaction on the growth,



yield and nutrition status of wheat, soil physicochemical properties and the association of AM fungi. It covered comparisons of compacted and non-compacted soil for five varieties of spring wheat. The specific objectives were to identify changes in soil bulk density and nutrient conditions; change in shoot biomass, grain yield, phosphorus and nitrogen status; AMF colonization, biomass indicators and diversity; and whether wheat variety affects the response to soil compaction.

2. Methodology

2.1 Study Design and Experimental Structure

A balanced factorial experimental design was used to determine the effect of soil compaction and wheat variety on soil physical, chemical and biological properties, crop performance, nutrient status and arbuscular mycorrhizal fungal (AMF) characteristics. Two soil treatments, compacted (C) and non-compacted (NC) were considered. Each soil condition was evaluated with 5 varieties of spring wheat (Alderon, Dacke, Dalavete, Diskett, Quarna). Five replications were available for each treatment x variety combination, resulting in a total of 40 observations, consisting of 20 observations when compacted and 20 when not compacted. A total of 8 observations were added for each variety, with 4 being compacted and 4 being non-compacted. The use of treatment, variety, replicate and plot identifiers ensured the correspondence between the soil, crop and AMF measurements. All of the soil variables used in the analysis were taken at the 0 to 10 cm sampling depth. The experimental design was then a 2 x 5 factorial with four replications for each treatment-variety combination.

2.2 Soil, Crop, Nutrient, and AMF Variables

The physical and chemical properties of the soil were evaluated by bulk density (g cm⁻³), soil pH, extractable phosphorus (P-AL; mg 100 g⁻¹ soil), nitrate nitrogen (NO₃-N; mg 100 g⁻¹ dry soil) and ammonium nitrogen (NH₄-N; mg 100 g⁻¹ dry soil). The main physical index used for the imposed soil-compaction condition was bulk density. Shoots biomass at flowering (g m⁻²), shoot P concentration (mg g⁻¹), shoot N concentration (g kg⁻¹) and grain yield (t ha⁻¹) were used as measures of wheat growth and nutrient status. The AMF responses were assessed as root AMF colonization (%), PLFA C16:1omega5 (microg g⁻¹) and NLFA C16:1omega5 (microg g⁻¹), virtual-taxon richness, Shannon diversity and Simpson diversity. Root colonization was the percentage of wheat root length with AM structures, PLFA and NLFA were measurements of fungal lipid biomarkers, respectively. The observations were n = 20 for each soil treatment in the treatment level descriptive statistics. Each mean for treatment x variety graphical comparisons was based on n = 4 replications.

2.3 Descriptive Statistics and Treatment Comparisons

Continuous variables were summarized using the arithmetic mean and standard deviation. The treatmentspecific mean was calculated as:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$$

where $\bar{x}$ represents the arithmetic mean, x_i represents the observed value, and $n=20$ for each overall treatment group.



The sample standard deviation was calculated as:

$$SD = \sqrt{\frac{\sum_{i=1}^m (x_i - \bar{x})^2}{n-1}}$$

Thus, the denominator for each treatment-specific standard deviation was $n-1=19$.

Differences between compacted and non-compacted soil treatments were assessed using two-sided independent-samples Student's t-tests with pooled variance. Separate treatment comparisons were performed for bulk density, soil pH, P-AL, NO₂-N, NH₄-N, shoot biomass, shoot P concentration, shoot N concentration, grain yield, AMF colonization, PLFA C16:1w5, NLFA C16:1wS, virtual-taxon richness, Shannon diversity, and Simpson diversity.

The test statistic was calculated as:

$$t = \frac{\bar{x}_C - \bar{x}_{NC}}{s_P \sqrt{\frac{1}{n_C} + \frac{1}{n_{NC}}}}$$

where IC and INC represent the compacted and non-compacted treatment means, respectively, $n_C = n_{NC} = 20$, and s_P represents the pooled standard deviation.

The pooled variance was calculated as:

$$s_P^2 = \frac{(n_C - 1)s_C^2 + (n_{NC} - 1)s_{NC}^2}{n_C + n_{NC} - 2}$$

The degrees of freedom for each treatment comparison were:

$$df = n_C + n_{NC} - 2 = 38$$

These treatment-level tests produced the p-values reported for the soil, crop, nutrient, and AMF variables.

2.4 Factorial Analysis of Soil Compaction and Wheat Variety

To assess the independent and combined effects of soil compaction and wheat variety, separate two-factor factorial linear models with two-way analysis of variance (ANOVA) were fitted for grain yield, shoot biomass, shoot P concentration, shoot N concentration, and AMF colonization. No separate correlation or simple regression analysis was applied because the reported inferential results were based on treatment, variety, and treatment $\times$ variety effects.

For each dependent variable, the factorial model was specified as:

$$Y_{ijk} = \mu + T_i + V_j + (T \times V)_{ij} + \varepsilon_{ijk}$$



where Y_{ijk} represents the observed response, μ is the overall mean, T_i represents the fixed effect of soil-compaction treatment, V_j represents the fixed effect of wheat variety. $(T \times V)_{ij}$ represents the interaction between treatment and variety, and ε_{ijk} represents residual error.

The equivalent regression representation was:

$$Y = \beta_0 + \beta_1(\text{Treatment}) + \beta_2(\text{Variety}) + \beta_3(\text{Treatment} \times \text{Variety}) + \varepsilon$$

Each factorial model used $N=40$ observations, distributed across 10 treatment $\times$ variety cells with four replicates per cell. The ANOVA degrees of freedom were therefore 1 for treatment, 4 for variety, 4 for the treatment $\times$ variety interaction, and 30 for residual error.

The test statistic for each ANOVA effect was calculated as:

$$F = \frac{MS_{\text{minet}}}{MS_{\text{extrur}}}$$

where:

$$MS_{\text{flit}} = \frac{SS_{\text{minet}}}{df_{\text{enect}}}$$

and:

$$MS_{\text{mock}} = \frac{SS_{\text{mix}}}{30}$$

Thus, treatment effects were evaluated using $F(1,30)$, whereas variety and treatment $\times$ variety effects were evaluated using $F(4,30)$.

2.5 Missing Data, Statistical Significance, and Ethical Considerations

The data were screened for completeness prior to statistical analysis for all soil, crop, nutrient and AMF data presented in tables and figures. There were no missing values in the variables analysed. All of the 40 observations were therefore used for all analyses, with none being discarded due to missing data, and no imputation procedure being needed. Twenty observations were always used for overall treatment comparisons and 20 observations for factorial analysis except that 30 residual degrees of freedom were used in the latter. All statistical tests were conducted two-tailed and significance was set at p values < 0.05 . Probabilities less than 0.001 were given as $p < 0.001$, others were given to three decimal places. Data are presented as mean $\pm$ SD. The study used secondary analysis of past collected measurements of agronomic, soil, plant and fungal parameters. There was no human participation, personally identifiable information or vertebrate animals involved, so the informed consent of humans and related ethics did not need to be considered.

3. Results

3.1 Effects of Soil Compaction on Soil Physicochemical Properties

The compaction of the soil resulted in a distinct change in physical soil condition. The mean bulk density changed from 1.068 ± 0.062 g cm⁻³ when the soil was kept in non-compacted condition to



1.167 +/- 0.069 g cm⁻³ when the soil was compacted, and the difference was statistically significant at $p < 0.001$ (Table 1). There was also a significant difference between the soil nitrate content in compacted and non-compacted plots, with the former showing a higher concentration (7.561 mg 100 g⁻¹ dry soil to 4.566 mg 100 g⁻¹ dry soil, $p = 0.024$). Ammonium-N was almost twice as high under compaction, although the difference was marginally non-significant ($p = 0.051$). Soil pH and extractable P, on the other hand, tended to be lower in compacted soil, but were not different from that of uncompacted soil at the 0.05 level of significance.

Table 1. Soil physicochemical characteristics under compacted and non-compacted conditions

Soil parameter	Compacted, mean +/- SD	Non-compacted, mean +/- SD	p-value
Bulk density (g cm ⁻³)	1.167 +/- 0.069	1.068 +/- 0.062	<0.001
Soil pH	5.595 +/- 0.173	5.695 +/- 0.147	0.056
P-AL (mg 100 g ⁻¹)	4.150 +/- 0.699	4.630 +/- 0.812	0.053
NO ₃ -N (mg 100 g ⁻¹ dry soil)	7.561 +/- 4.260	4.566 +/- 3.764	0.024
NH ₄ -N (mg 100 g ⁻¹ dry soil)	1.522 +/- 1.369	0.768 +/- 0.949	0.051

The treatment-associated change in soil physical condition is illustrated in Figure 1, where compacted soil exhibited consistently greater mean bulk density than non-compacted soil.

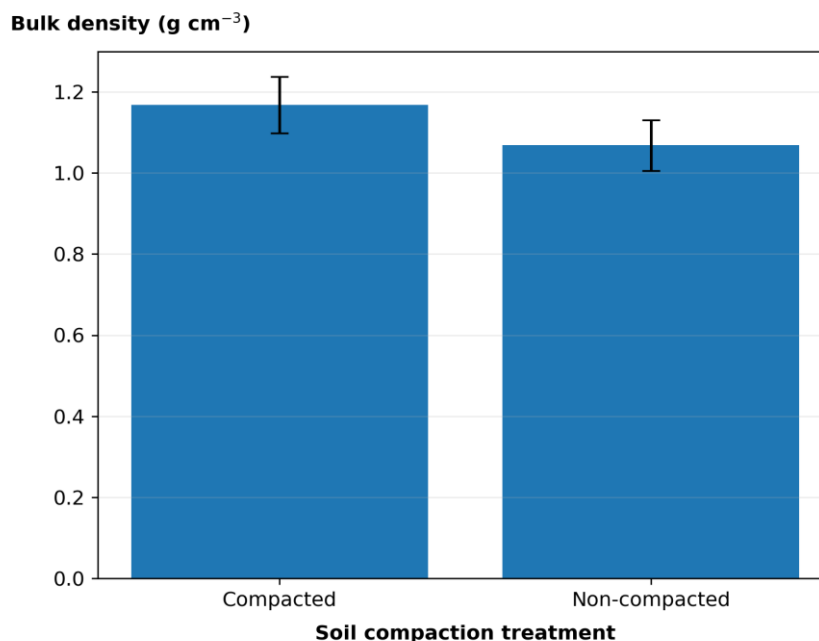


Figure 1. Mean soil bulk density under compacted and non-compacted treatments

3.2 Wheat Growth, Grain Yield, and Nutrient Status

Compared to other wheat plant parameters, compaction had relatively little effect on wheat biomass and grain production, but was correlated with significant variation in shoot nutrient concentrations. As presented in Table 2, mean shoot biomass was 396.91 +/- 84.42 g m⁻² in compacted soil and 410.42 +/- 73.84 g m⁻² in non-compacted soil, with no significant difference ($p = 0.593$). Similarly, compaction reduced mean grain yield from 2.660 to 2.475 t ha⁻¹ but this difference was not statistically significant ($p = 0.444$). However, shoot P concentration in compaction was significantly higher than in non-compaction ($p = 0.002$) with the value of 1.537 +/- 0.244 mg g⁻¹ and 1.310 +/- 0.172 mg g⁻¹ respectively. Shoot N concentration also increased significantly, from 15.037 +/- 1.011 to 16.037 +/- 0.931 g kg⁻¹ ($p = 0.002$).

Table 2. Wheat growth, yield, and nutrient status according to soil-compaction treatment

Wheat parameter	Compacted, mean +/- SD	Non-compacted, mean +/- SD	p-value
Shoot biomass (g m ⁻²)	396.91 +/- 84.42	410.42 +/- 73.84	0.593



Wheat parameter	Compacted, mean +/- SD	Non-compacted, mean +/- SD	p-value
Shoot P (mg g ⁻¹)	1.537 +/- 0.244	1.310 +/- 0.172	0.002
Shoot N (g kg ⁻¹)	16.037 +/- 0.931	15.037 +/- 1.011	0.002
Grain yield (t ha ⁻¹)	2.475 +/- 0.659	2.660 +/- 0.844	0.444

As shown in Figure 2, there were significant differences in yield among varieties. Alderon produced highest yield in both the soil types, yielding around 3.50 t ha⁻¹ when the soil was compacted and 4.11 t ha⁻¹ when the soil was not compacted. Moderate differences in treatment were shown with Quarna while comparatively small differences were shown for Dacke, Dalavete and Diskett.

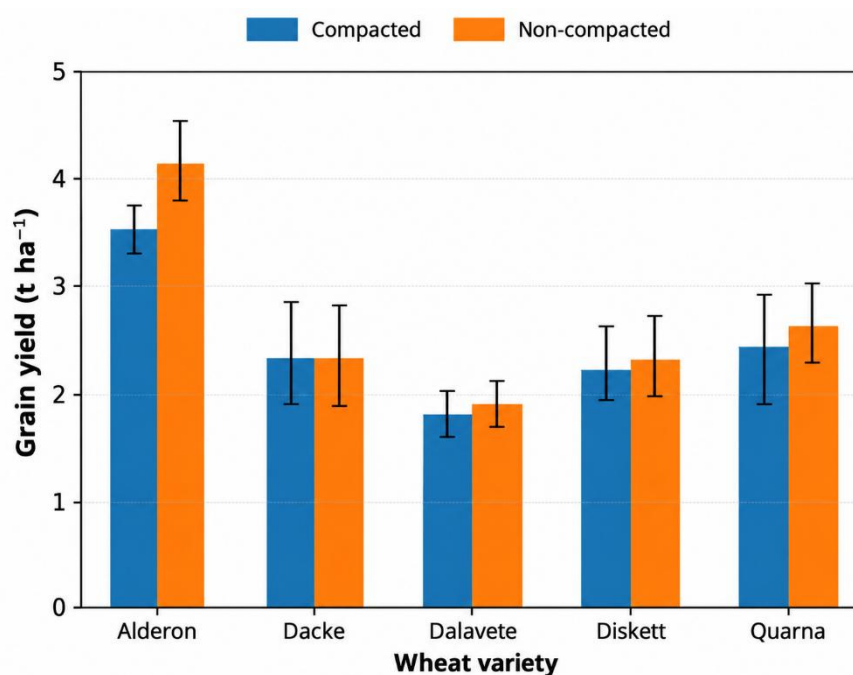




Figure 2. Grain yield of five spring-wheat varieties under compacted and non-compacted soil conditions

The distribution of shoot P and N concentrations among the varieties is shown in Figure 3. All five varieties had higher levels of Shoot P under compaction. This difference was highlighted especially in Dacke and Quarna. This was a comparable response for shoot N, and in general, the N concentrations were higher in plants grown under compacted conditions than under non-compacted conditions.

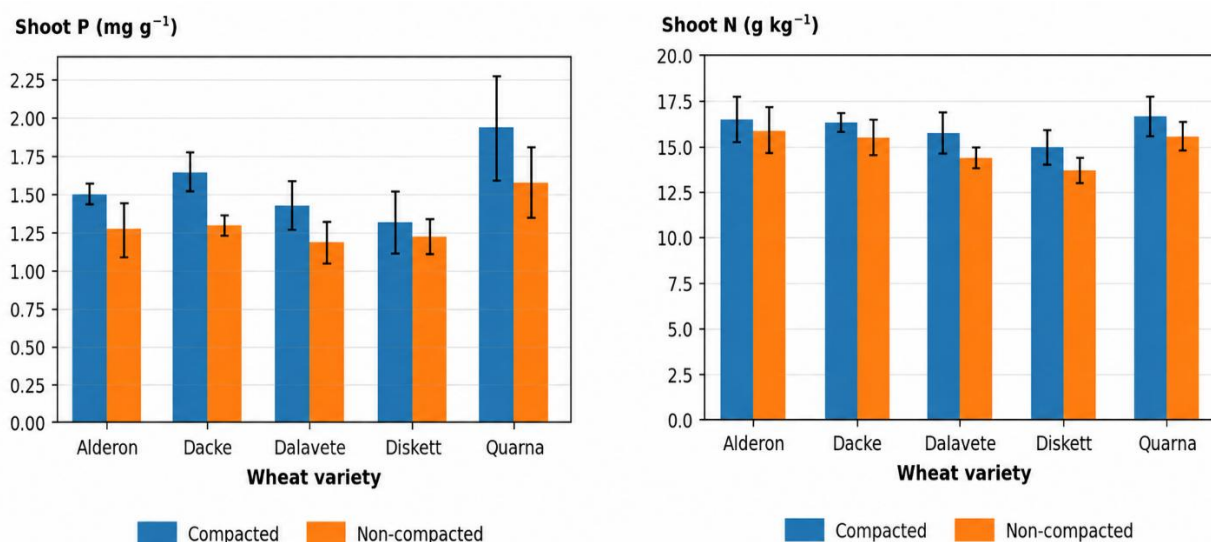


Figure 3. Shoot phosphorus and nitrogen concentrations of wheat varieties under compacted and non-compacted soil conditions

3.3 Arbuscular Mycorrhizal Colonization, Biomass, and Diversity

There was no difference between treatments ($p = 0.247$) in mean root colonization ($18.95 \pm 15.35\%$ under non-compacted conditions, and $24.90 \pm 16.61\%$ under compacted conditions). PLFA C16:1omega5 was also not significantly different between the treatments. Table 3 shows that the abundance of NLFA C16:1omega5 was higher in non-compacted soil, while the abundance of AMF and Shannon and Simpson diversity were generally similar between the soil treatments.

Table 3. Arbuscular mycorrhizal fungal characteristics under the two soil-compaction treatments



AMF parameter	Compacted, mean +/- SD	Non-compacted, mean +/- SD	p-value
Root AMF colonization (%)	24.90 +/- 16.61	18.95 +/- 15.35	0.247
PLFA C16:1omega5 (microg g-1)	17.149 +/- 8.488	17.790 +/- 11.244	0.840
NLFA C16:1omega5 (microg g-1)	82.629 +/- 56.656	104.218 +/- 102.390	0.416
VT richness	22.006 +/- 4.938	22.782 +/- 5.356	0.637
Shannon diversity	6.501 +/- 1.518	6.261 +/- 1.600	0.630
Simpson diversity	4.949 +/- 1.366	4.600 +/- 1.632	0.468

The overall compaction effect was not significant, but there was significant cultivar-specific variation in AMF colonization as shown in Figure 4. Under compaction, the mean colonization of Alderon soil was 46.00% compared to 14.25% under non-compacted soil, showing the clearest response. Dacke's increase was smaller, and Dalavete, Diskett and Quarna had little direction indicated.

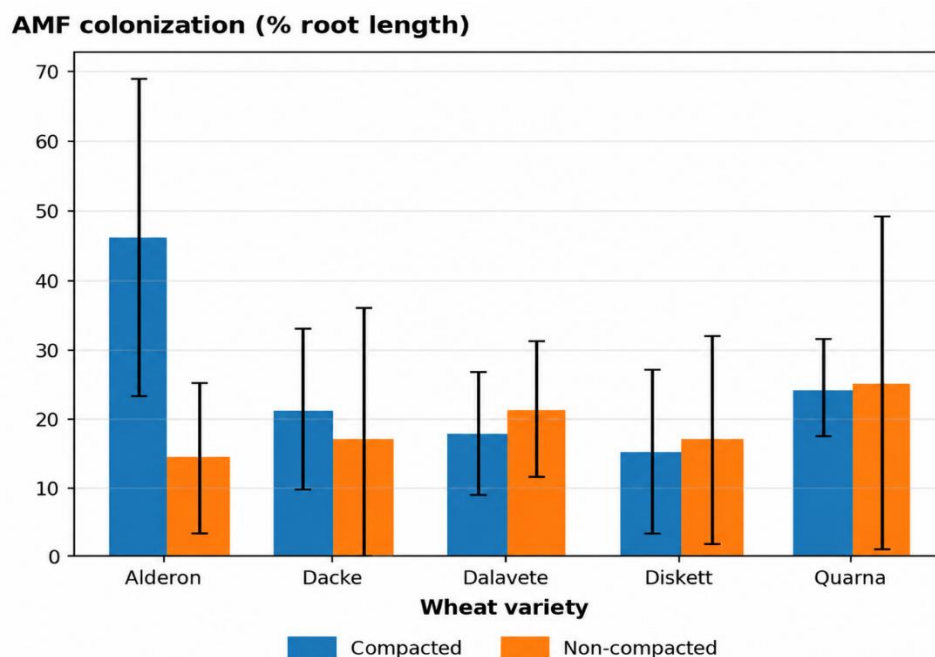


Figure 4. Arbuscular mycorrhizal fungal root colonization of five wheat varieties under compacted and non-compacted soil conditions

3.4 Treatment, Variety, and Treatment On Variety Effects

Two factor analysis showed that the observed crop response was more strongly related to the wheat variety for certain parameters than to soil compaction. Soil compaction did not significantly affect yield ($F = 2.587$, $p = 0.118$), while the effect of the varieties was highly significant ($F = 32.539$, $p < 0.001$) as summarized in Table 4. Shoot biomass and Treatment x variety interaction were not significant. Variety and compaction, however, had significant effects on plant nutrient status. Shoot P ($F = 21.585$, $p < 0.001$) and shoot N ($F = 16.611$, $p < 0.001$) were significantly affected by compaction and variety. None of the treatment x variety interactions for P or N were significant. The colonization by AMF was not significantly affected by the overall treatment effect or by the variety effect, although there was a relatively high but not significant increase in colonization tendency due to the treatment x variety interaction ($F = 1.852$, $p = 0.145$).

Table 4. Two-factor ANOVA of soil compaction, wheat variety, and their interaction

Response variable	Effect	F	p-value
Grain yield	Compaction treatment	2.587	0.118
	Variety	32.539	<0.001
	Treatment x Variety	1.020	0.413



Response variable	Effect	F	p-value
Shoot biomass	Compaction treatment	0.253	0.618
	Variety	0.723	0.583
	Treatment x Variety	0.073	0.990
Shoot P	Compaction treatment	21.585	<0.001
	Variety	9.519	<0.001
	Treatment x Variety	0.754	0.564
Shoot N	Compaction treatment	16.611	<0.001
	Variety	7.060	<0.001
	Treatment x Variety	0.357	0.837
AMF colonization	Compaction treatment	1.515	0.228
	Variety	1.049	0.399
	Treatment x Variety	1.852	0.145

The overall results suggest that the compaction treatment succeeded in increasing the bulk density of the soil and changing the condition of soil mineral-N. These changes did not significantly affect overall treatment mean total shoot biomass or grain yield but were correlated with significantly increased shoot P and N concentrations. AMF colonization and fungal biomass indicators did not change significantly at the treatment level though there was a different response among cultivars, with AMF colonization significantly increasing in Alderon showing the contrasting response to compacted soil, suggesting that wheat genotype may affect plant-AMF response to compacted soil.

4. Discussion

The present findings show that a major change in the physical soil environment occurred due to soil compaction and that there was no corresponding overall reduction in the wheat biomass or yield. Bulk density was significantly higher for compaction treatment indicating that compaction had created a significant physical constraint. This trend is supported by experimental results indicating that both biological and soil-management practices can have a significant impact on the response of crops to compacted soil and that bulk density is a useful indicator of compaction severity (Hejazi Mahabadi et al., 2025). This suggests that moderate physical deterioration does not immediately entail proportional



loss in productivity; if other crop genotypes are available and nutrient-acquisition mechanisms are compensatory, then no overall yield reduction can be expected.

Mineral-N status of the soils also varied among treatments. Nitrate concentration was significantly higher when the soil was compacted and ammonium was near significantly higher when the soil was compacted. These may be caused by changes in soil aeration, moisture uptake, microbial breakdown, and root uptake of nutrients in compacted soil. Similarly, differences in soil resource environment caused by management practices, such as tillage and nutrient application, have been found to have impacts on the quality and responses of wheat (Farad et al., 2025). The current results indicate that soil nutrient concentration can not be assessed without considering plant uptake and interaction with soil microbes.

One of the key results was the large number of significant increases in shoot P and N concentrations under compaction, in the absence of any significant treatment effects on shoot biomass or grain yield. Mycorrhizal systems can adapt their nutrient uptake in soil of limiting quality and nutrient status of plants has been improved in various cropping systems using the AMF (Sakthiaswari et al., 2022). Wheat studies also show that AM symbiosis has the potential to affect wheat yield components and crop responses to phosphorus fertilization (Saheed & Darwesh, 2021). Likewise, physical management, organic matter, and mycorrhizal fungi have been linked to changes in the nutrient-use efficiency, highlighting the close connection between physical management and biological nutrient acquisition (Feilinezhad et al., 2022).

The AMF results offer more insight. No significant differences in overall root colonization, PLFA and NLFA biomarkers, richness, Shannon diversity or Simpson diversity were found between the compacted and non-compacted treatments. This means that compaction was not equally effective at reducing AM fungal abundance and community-level diversity. The structure of AMF fungi and plant growth can be affected differently when management is altered, indicating that the abundance of AMF fungi does not have to follow its diversity and benefit to plants (Zhou et al., 2025). The results are also consistent with other studies that have shown AMF can enhance soil biological properties and nutrient status despite production of varying responses under different environmental conditions and host plants (Al-Maliki et al., 2021).

Cultivar-level was the strongest pattern among the biological levels. The AMF root colonization of Alderon was significantly higher than the other varieties under compaction while some varieties exhibited relatively small differences. This corroborates the hypothesis that the ability to uptake nutrients through AM fungal networks varies between spring-wheat cultivars in FCS (Torppa et al., 2023). When AMF are used with phosphorus availability and root growth, differences in the response of crops to mycorrhizal associations have been reported as well (Christensen et al., 2022). In general, AMF response to nutrients is highly variable across plant species and soils, and this is reflected in response to nutrient and contaminant stress (Liu et al., 2020). Variability in growth and nutrient uptake has also been noted between plants growing under stressed soils under AMF (Nasiri et al., 2022).

This small overall impact of compaction on yield thus suggests that this trend is consistent with a system where cultivar-dependent root and soil microbial strategies help to reduce the impact of soil physical stress. The role of biological facilitation in nutrient-poor soils is further reinforced by improvements in wheat performance with both mycorrhizal and soil amendment strategies (Khdir & Rahman, 2024). Similarly, other cereals under nutrient limitation have also benefited from beneficial



microbial interactions that have facilitated crop growth (Aliyat et al., 2024). Using AMF along with organic amendments could also positively affect the soil microbial activities and crop production under stressful conditions (El-Maghraby et al., 2024). The overall results have suggested that soil compaction is a physical factor to be taken into account, as well as being an interactive factor related to wheat genotype, soil nutrient dynamics and mycorrhizal function.

5. Conclusion

The present study showed that soil compaction had a significant effect on the physical and nutritional environment for spring wheat, but had mixed effects on crop productivity and arbuscular mycorrhizal fungal responses. The bulk density and nitrate level were significantly higher for compacted soil, indicating measurable soil condition change. The overall shoot biomass and grain yield were not significantly different between compacted and non-compacted treatments, however. However, in contrast, the concentration of phosphorus and nitrogen in the shoots was significantly elevated under compaction, suggesting that nutrient status may have a different response than aboveground growth and yield. At the overall level, the arbuscular mycorrhizal fungal colonization, the lipid biomarkers and diversity indices were not significantly different between the two soil treatments. Differences between cultivars were, however, evident with significant amplification of AMF colonization in Alderon when cultivation was done under compacted conditions. The results indicate that the ability to establish or increase mycorrhizal relationships in the face of soil physical stress might differ among wheat cultivars. In general, the study emphasizes that soil compaction has a complex and multi-faceted impact on wheat, rather than a consistent yield loss. The differences noted among the varieties suggest that genotype of the crop be taken into account when assessing the soil-compaction tolerance and AMF mediated nutrient acquisition. The results of this work confirm the relevance of combining soil physical management, cultivar and rhizosphere biological processes for sustainable wheat production.

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