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Comparative effects of deep ploughing and disking on soil properties and yield of winter wheat (*Triticum aestivum* L.) in Yernjatap, Armenia

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Abstract. Soil tillage practices play a crucial role in maintaining soil fertility and ensuring sustainable agricultural production under rainfed conditions. This study evaluated the effects of conventional (deep ploughing, 20–22 cm) and shallow tillage (disking, 10–12 cm) on soil properties, nutrient availability, and the yield and grain quality of winter wheat (*Triticum aestivum* L.), cultivar 'Tanya', in Yernjatap settlement, Aragatsotn region, Armenia. The experiment was conducted during 2022–2024 using a randomized design with three replications. Shallow tillage improved soil structure and fertility, increasing humus content (up to 4.19%) and water-stable aggregates (up to 55.1%), while conventional tillage resulted in a decline in humus in the upper soil layer. Nutrient availability was also enhanced under disking, with available phosphorus increasing from 2.72 to 3.94 mg 100 g^{-1} and potassium reaching 40.64 mg 100 g^{-1} in the 0–20 cm layer. In contrast, both nutrients decreased under deep ploughing. Soil pH, electrical conductivity, and soluble salts were not significantly affected by tillage practices. Improved soil conditions under disking led to enhanced plant growth, higher biomass accumulation, and increased survival rates, exceeding deep ploughing by up to 13.9%. Grain yield was significantly higher under disking in 2024, reaching 1.71 t ha^{-1} compared to 1.39 t ha^{-1} under ploughing, representing a 23.0% increase ($P = 0.003$). Straw yield also increased by 21.4%. The results demonstrate that shallow tillage is a more effective and sustainable practice for improving soil fertility, enhancing winter wheat productivity, and supporting stable crop production under rainfed mountainous conditions.

Key words: deep ploughing, disking, grain yield, rainfed agriculture, winter wheat.

INTRODUCTION

The yield and grain quality of cereal crops, particularly winter wheat (*Triticum aestivum L.*), are strongly influenced by agrotechnical practices and environmental conditions, among which soil moisture availability plays a decisive role. In rainfed

agricultural systems, water deficit is often the primary factor limiting crop productivity, especially in semi-arid and mountainous regions.

In several agricultural regions of Armenia, including Aragatsotn winter wheat is widely cultivated under rainfed conditions, where crop production depends entirely on natural precipitation. As a result, crop productivity is highly variable and generally lower than its potential. According to regional data, cereal yields in irrigated areas range between 2.5 and 4.0 t ha^{-1}, whereas under rainfed conditions they are significantly lower, ranging from 1.0 to 2.0 t ha^{-1} (Matevosyan & Gyulkhasyan, 2000; Aparan Community Development Program, 2018–2022). This substantial yield gap highlights the critical role of soil moisture in determining crop performance.

Yernjatap village, located on the south-eastern slopes of Mount Aragats at an altitude of 1,800–1,900 m (average ~1,850 m), belongs to the mountain-steppe zone characterized by limited and irregular precipitation (Yernjatap Community Development Council, 2017). Under these conditions, soil moisture conservation becomes a key factor in ensuring stable crop production. Since irrigation is not practiced in this area, appropriate tillage systems play a crucial role in improving water retention and supporting crop productivity.

Previous studies have demonstrated that different tillage practices significantly affect water dynamics, soil structure, and crop yield. Conventional tillage (deep ploughing), although effective for weed control and seedbed preparation, significantly increases soil disturbance and can accelerate water loss (Hemmat & Eskandari, 2004; Kaftan & Zenkova, 2019; Dong et al., 2024).

In contrast, conservation and shallow tillage practices have been shown to improve water retention and enhance water use efficiency by reducing evaporation and maintaining soil surface cover (Kolkova, 2017; Mamatodzhiyev & Mamayusipova, 2020; Woźniak & Rachoń, 2020; Turusov et al., 2021). Experimental studies conducted under rainfed conditions indicate that reduced tillage systems can increase soil water content and stabilize wheat yields compared to conventional methods (Woźniak & Rachoń, 2020; Sun et al., 2022; Buczek et al., 2023; Liu et al., 2025).

Despite these findings, there is limited information on the comparative effectiveness of **conventional** and shallow tillage practices under the specific soil and climatic conditions of high-altitude rainfed regions in Armenia. In particular, the influence of these practices on yield performance and grain quality of winter wheat in the mountain-steppe zone remains insufficiently studied.

Therefore, the objective of this study was to evaluate the effects of conventional and shallow tillage on the yield and grain quality of winter wheat (*Triticum aestivum* L.), cultivar Tanya, under rainfed conditions in Yernjatap village, Aragatsotn region. The results of this study are expected to contribute to the identification of optimal tillage practices for improving soil moisture conservation, enhancing crop productivity, and promoting sustainable wheat production in mountainous rainfed environments.

MATERIALS AND METHODS

Study area and climate

The study was conducted from 2021 to 2024 in Yernjatap village, Aragatsotn region, Armenia, under rainfed conditions. The area is characterized by a temperate

mountainous climate with long, cold winters and warm, relatively moist summers. Climatic data were obtained from the nearest Aparan Hydrometeorological Station. During 2021–2024, annual mean air temperatures in Yernjatap ranged from approximately +6.4 to +6.8 °C, while total annual precipitation varied between 510 and 670 mm, with slightly higher rainfall recorded in 2023–2024. Most precipitation occurred during spring and autumn (Fig. 1.) (Hydrometeorology and Monitoring Center of the Ministry of Environment of the Republic of Armenia, 2024).

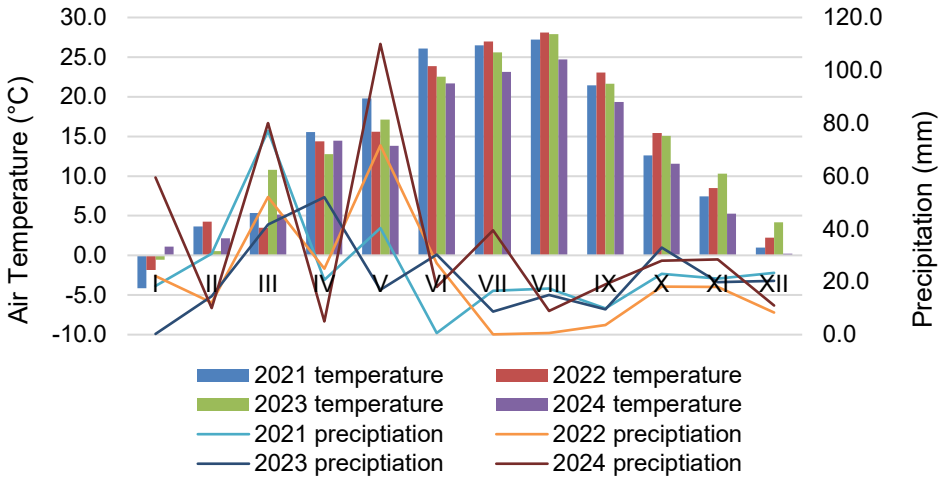


Figure 1. Monthly precipitation and mean air temperature during the experimental period (2021–2024), according to data from the Aparan Hydrometeorological Station. Air temperature is shown as bars, while precipitation is presented as a line (polygon).

Soils are predominantly brown, with humus content of 3.0–4.2% and depth of 35–55 cm. Soil reaction is slightly alkaline, and the cation exchange complex contains up to 20% exchangeable sodium. The soils are mainly of medium to heavy sandy loam texture and are typically dusty at the surface (Melkonyan et al., 2004; Atlas of soils of the Republic of Armenia, 1990; Ghazaryan & Kroyan, 2019).

Experimental design

The experimental field covered ≈ one ha, divided into six plots of 1,500 m² each excluding buffer zones (Fig. 2) (Mamajanyan, 2018; Dechassa et al., 2022).

Two tillage treatments were evaluated in a randomized design with three replications:

1. Conventional tillage: deep ploughing (20–22 cm)
2. Shallow tillage: disking (10–12 cm)

Primary tillage was performed using a mounted three-bottom mouldboard PLN-3 plough. Shallow tillage was carried out using a disc harrow (Bomet type) with a working width of approximately 1.5 m, equipped with 14 discs arranged in two rows. All tillage operations were conducted using a MTZ Belarus 82,1 tractor (81 hp). Field operations were carried out at an average working speed of 4–6 km h^{-1}, and the same machinery was used for all treatments throughout the study period.

To minimize edge effects, buffer zones were incorporated into the experimental layout. A 5 m buffer zone was maintained along the entire perimeter of the experimental field, while 3 m buffer zones were established between blocks (replications) and 2 m buffer zones between plots within each block.

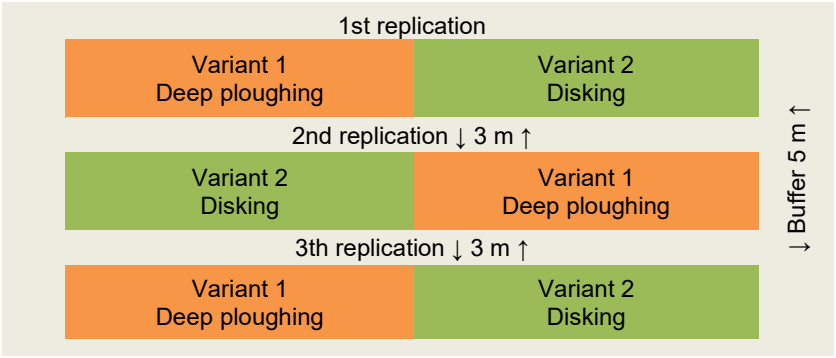


Figure 2. Schematic diagram of the experimental design (randomized complete block design) with two tillage treatments.

Winter wheat (*Triticum aestivum L.*), cultivar 'Tanya', was grown continuously in the same experimental plots during the three-year study period, and no crop rotation was implemented. The crop was sown at a rate of 300–320 kg ha^{-1}, with sowing carried out in early September and harvesting performed in late August at full maturity (Matevosyan & Gyulkhasyan, 2000; Markosyan et al., 2024).

The relatively high seeding rate used in the experiment corresponds to recommended agronomic practices for mountainous regions of Armenia, where the optimal sowing density is 5.5–7.0 million viable seeds per hectare (Matevosyan & Gyulkhasyan, 2000). Under such conditions, higher seeding rates are applied to compensate for potential plant losses caused by low temperatures, frost heaving, and reduced field germination, ensuring adequate plant density and stable yield formation.

No mineral or organic fertilizers were applied throughout the experiment. In addition, no herbicides or fungicides were used, and no weed, pest, or disease control measures were implemented.

Uniform agronomic management was maintained across all treatments, with the only experimental factor being tillage depth. No additional soil tillage operations were carried out between primary tillage and sowing, except those defined by the experimental design.

During harvesting, the yield from buffer zones was collected separately and excluded from analysis, and yield measurements were taken only from the effective plot area.

Soil sampling and laboratory analyses

Soil samples were taken each year before sowing. For each treatment, samples were taken from three replications. Within each replication, three subsamples were collected at random points and combined to form one composite sample representative of the plot.

Soil samples were collected using a soil auger from 0–10 and 10–20 cm depths for determining physical and organic properties, and from 0–20 and 20–40 cm depths for assessing nutrient content, pH, soluble salts, and electrical conductivity (EC).

Laboratory analyses included the determination of soil texture using the Kaschinsky method, based on particle-size fractionation by sedimentation (Vadyunina & Korchagina, 1986). Humus content was determined by the Tyurin method, based on oxidation of organic matter using potassium dichromate in an acidic medium (Farsiyan & Yeritsyan, 2020).

Easily hydrolysable nitrogen was determined by the Tyurin-Kononova method, based on acid hydrolysis (Farsiyan & Yeritsyan, 2020). Available phosphorus was determined by the Machigin method using a 1% ammonium carbonate solution followed by colorimetric analysis (Farsiyan & Yeritsyan, 2020).

Exchangeable potassium was also determined by the Machigin method using a 1% ammonium carbonate solution, followed by measurement with a flame photometer (Vadyunina & Korchagina, 1986). Water-stable aggregates were determined by the Savinova method, which evaluates the stability of soil aggregates under wet sieving conditions (Vadyunina & Korchagina, 1986).

Soil reaction (pH), soluble salts, and electrical conductivity (EC) were determined in soil water extracts using a pH meter and an EC meter (Farsiyan & Yeritsyan, 2020; Soil Survey Staff, 2022).

Plant sampling and measurements

Plant survival was assessed during the growing season at the germination stage (autumn), tillering stage (spring), and maturation stage (summer). Prior to harvest, complete plant sampling was conducted from 1 m² plots, from the calculation areas. For each replicate, three 1 m² sample plots were randomly selected from different parts of the experimental area. For each treatment, the three initial samples from each replicate were combined to form a single composite sample, which was used for the measurement of biometric and yield parameters.

Parameters included:

- Aboveground and root biomass
- Stem and spike length
- Grain weight per spike and 1,000-grain weight
- Grain and straw yield and ratios.

Grain quality analysis included the determination of total nitrogen and crude protein using the Kjeldahl method, based on wet digestion, acid decomposition, distillation, and titration (Yeritsyan & Harutyunyan, 2009). Crude ash content was determined by the dry ashing method, involving combustion of the sample at high temperature in a muffle furnace to obtain mineral residue (Nenova et al., 2019). Crude fibre content was determined using the Henneberg-Stohmann method, based on sequential acid and alkaline digestion of organic matter (Yeritsyan & Harutyunyan, 2009). Phosphorus content was determined after Kjeldahl digestion using a photoelectrocolorimetric method. Potassium content was determined after wet digestion using flame photometry (Yeritsyan & Harutyunyan, 2009).

All analyses were carried out at the Organic Agriculture Laboratory of the Armenian National Agrarian University.

Statistical analysis

Data were analysed using standard statistical procedures. Mean values were calculated with standard deviation (*SD*) and standard error (*SE*). Differences between

treatments were assessed using the independent samples *t-test* at 5% significance level ($P \leq 0.05$). Statistical comparisons were performed only among tillage treatments within each year. Microsoft Excel was used for calculations, and significant differences are indicated by different letters (e.g. a, b) for ease of comparison.

RESULTS AND DISCUSSION

The study revealed that the tillage method had a significant impact on soil physical and chemical properties, particularly influencing organic matter accumulation and soil structural stability. Table 1 shows that under disking, humus content increased in both soil layers. In the 10–20 cm layer, it rose from 4.03% in 2022 to 4.15% in 2024, while in the 0–10 cm layer, it increased from 4.05% to 4.19% ($P < 0.05$). In parallel, the proportion of water-stable aggregates increased to 55.1% and 48.4% in the respective layers, confirming a positive relationship between organic matter accumulation and soil structural stability.

Table 1. Effect of different tillage methods on soil humus content, clay fraction, and water-stable aggregate proportion

Tillage method	Depth, cm	Humus content (%)			Clay fraction (< 0.01 mm, %)			Water-stable aggregates (> 0.25 mm, %)		
		2022	2023	2024	2022	2023	2024	2022	2023	2024
Deep ploughing	0–10	4.06^{a}	4.06^{a}	3.90^{b}	48.20^{b}	47.90^{b}	48.40^{a}	44.10^{a}	43.90^{a}	44.00^{a}
Disking		4.05^{a}	4.10^{a}	4.19^{a}	51.40^{a}	50.30^{a}	48.81^{a}	46.60^{b}	47.40^{b}	48.40^{b}
Deep ploughing	10–20	4.00^{a}	4.01^{a}	3.81^{b}	49.10^{b}	49.00^{b}	49.10^{b}	44.80^{a}	44.70^{a}	44.80^{a}
Disking		4.03^{a}	4.11^{a}	4.15^{a}	55.90^{a}	56.10^{a}	55.13^{a}	51.30^{b}	53.90^{b}	55.10^{b}

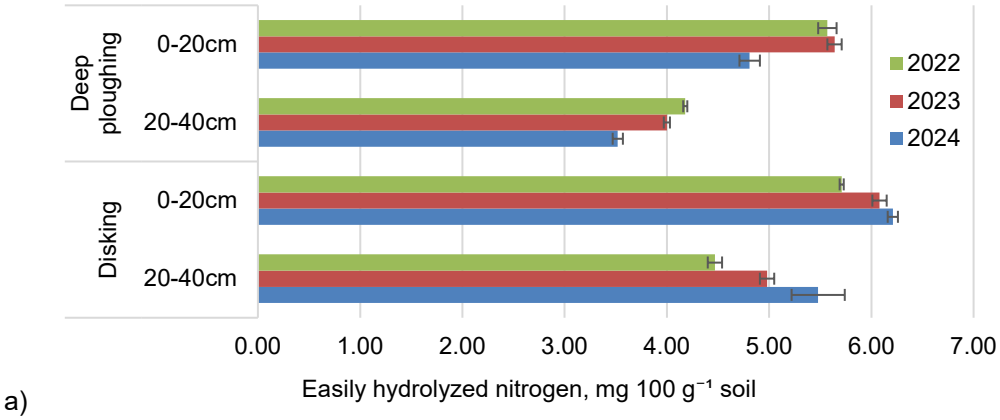
Note. Different letters within a column indicate significant differences between tillage methods (*t-test*, $P < 0.05$).

In contrast, under conventional ploughing humus content decreased in the 0–10 cm layer (from 4.06% in 2022 to 3.90% in 2024, $P < 0.05$), while water-stable aggregates remained almost unchanged (44.1–44.8%). Although detailed aggregate size distribution may provide additional insights, the proportion of water-stable aggregates (> 0.25 mm) is widely recognized as a reliable indicator of soil structural stability and has been effectively used to assess tillage impacts in previous studies (Vadyunina & Korchagina, 1986; Diop et al., 2024). These findings indicate that shallow tillage better preserves soil fertility and improves physical stability. Similar trends were reported in earlier studies, where conservation tillage enhanced soil aggregation and improved aggregate stability (Kolkova, 2017; Kaftan & Zenkova, 2019; Mamatodzhiyev & Mamayusipova, 2020; Pavlichenko et al., 2023; Phefadu & Munjonji, 2024).

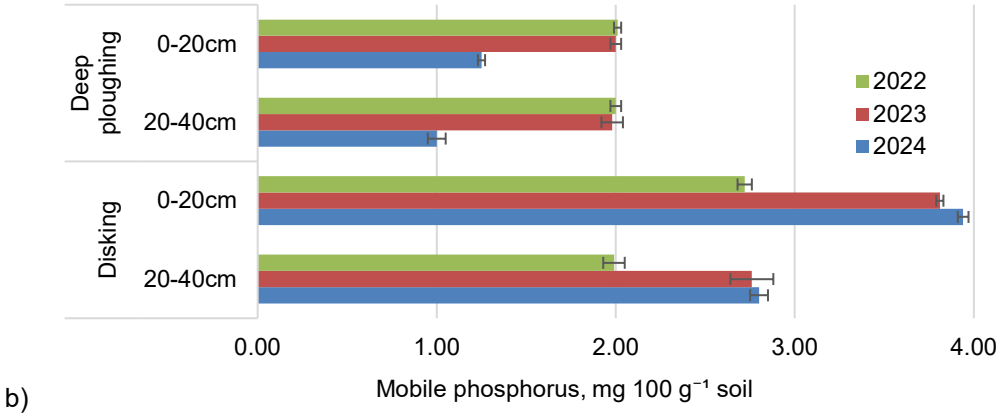
Clay fraction (< 0.01 mm) showed only minor variations under different tillage treatments over the study period. Under disking, the values changed slightly from 48.20% in 2022 to 48.40% in 2024, corresponding to an increase of approximately 0.4%. In contrast, under conventional tillage, clay content decreased from 51.40% in 2022 to 48.81% in 2024, representing a reduction of about 5.0%.

Overall, the observed changes were relatively small, indicating that tillage practices had a limited effect on the clay fraction. However, the slight stabilization of fine particles

under reduced tillage may suggest improved soil aggregation, which is consistent with previous findings (Kolkova, 2017; Kaftan & Zenkova, 2019; Khusaynov et al., 2020).



a)



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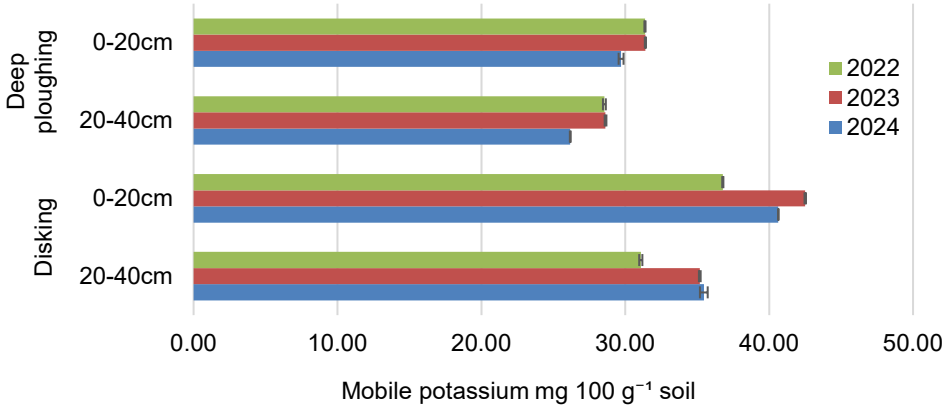

c)

Figure 3. Available soil nutrients under different tillage practices: a) Easily hydrolyzed nitrogen, b) Mobile phosphorus, c) Mobile potassium, across years (2022–2024) and soil depths (0–20, 20–40 cm), mg 100 g^{-1} soil.

Note to the Figure. Values are presented as mean ± standard error (*SE*).

Shallow tillage also influenced nutrient dynamics (Woźniak & Rachon, 2020; Khusaynov et al., 2022, Litvinova et al., 2023; Diop et al., 2024; Calistru et al., 2024). Nitrogen content under disking increased steadily in the 0–20 cm layer from 5.71 to 6.21 mg 100g^{-1} and in the 20–40 cm layer from 4.47 to 5.48 mg 100g^{-1}, while conventional ploughing led to a decrease from 5.57 to 4.81 mg 100g^{-1} g in 0–20 cm $P < 0.05$ for 2023–2024 (Fig. 3, a).

Available phosphorus content decreased under ploughing, with values dropping from 2.01 to 1.25 mg 100 g^{-1} in the 0–20 cm layer and from 2.00 to 1.00 mg 100 g^{-1} in the 20–40 cm layer, showing a statistically significant decline ($P < 0.01$). In contrast, disking led to an increase in phosphorus content in both soil layers, rising from 2.72 to 3.94 mg 100 g^{-1} in the 0–20 cm layer and from 1.99 to 2.80 mg 100 g^{-1} in the 20–40 cm layer, suggesting enhanced P_2O_5 accumulation and improved topsoil stabilization (Fig. 3, b).

Potassium content showed a similar pattern. Under conventional ploughing, potassium levels decreased from 31.37 to 29.71 mg 100 g^{-1} in the 0–20 cm layer and from 28.55 to 26.18 mg 100 g^{-1} in the 20–40 cm layer. Conversely, disking increased potassium content in both layers, reaching 40.64 mg 100 g^{-1} in the 0–20 cm layer and 35.46 mg 100 g^{-1} in the 20–40 cm layer, indicating a positive effect on soil nutrient enrichment (Fig. 3, c).

Soil pH (7.05–7.20), soluble salts (< 0.025%), and electrical conductivity (79.5–86.6 μS cm^{-1}) did not differ significantly between treatments, indicating that these parameters were not limiting factors for winter wheat growth under the experimental conditions (Bekele, 2020; Dechassa et al., 2022).

The observed improvements in soil properties were reflected in crop growth and yield. Disking resulted in consistently higher plant height, aboveground and root biomass, number of tillers per spike, spike length, and 1,000-grain weight across 2022–2024. Some parameters, such as grain weight per spike in 2022 and root biomass in 2024, showed statistically significant differences ($P < 0.05$). In 2024, root biomass under disking reached 202.03 g, and spike length was 7.61 cm, indicating more active biological development (Table 2), consistent with previous studies (Gaile et al., 2017; Woźniak & Rachon, 2020) reporting similar improvements in winter wheat growth and grain quality under comparable tillage systems.

Table 2. The effect of different tillage methods on the growth, development, and yield components of winter wheat

Year	Tillage method	Stem height, cm	Aboveground biomass, g	Root biomass, g	Number of spike-bearing stems	Spike length, cm	Grain weight per spike, g	1,000-grain weight, g
2022	Deep ploughing	53.44^{b}	507.10^{b}	137.40^{b}	247.60^{b}	5.34^{a}	0.47^{b}	42.81^{a}
	Disking	56.13^{a}	512.20^{a}	149.13^{a}	252.40^{a}	6.31^{a}	0.58^{a}	42.97^{a}
2023	Deep ploughing	61.71^{a}	516.43^{b}	151.91^{b}	253.64^{a}	6.12^{b}	0.54^{b}	44.01^{a}
	Disking	63.21^{a}	520.33^{a}	171.41^{a}	255.32^{a}	6.73^{a}	0.60^{a}	44.27^{a}
2024	Deep ploughing	61.42^{a}	528.43^{a}	184.02^{b}	274.62^{b}	6.18^{b}	0.57^{a}	44.58^{a}
	Disking	63.00^{a}	531.75^{a}	202.03^{a}	278.50^{a}	7.61^{a}	0.64^{a}	45.31^{a}

Note. Different letters within a column indicate significant differences between tillage methods (*t-test*, $P < 0.05$).

These data further indicate that under disking, the improvement of soil physical structure before harvest, the number of surviving plants under disking exceeded that under deep ploughing by 10.4%, 3.6%, and 13.9% in 2022, 2023, and 2024, respectively (Table 3).

Table 3. Effect of different tillage methods on the survival of winter wheat plants

Year	Tillage method	Number of emerged seedlings, pcs m^{-2}	Germination rate, %	Number of surviving plants, pcs m^{-2}			Number of surviving plants, %
				Late autumn	Early spring	Before harvest (August)	
2022	Deep ploughing	580.53[a]	82.93[a]	408.02[b]	351.72[b]	298.33[b]	51.39[b]
	Disking	550.44[b]	78.63[b]	439.00[a]	382.00[a]	329.30[a]	59.82[a]
2023	Deep ploughing	538.53[a]	76.93[a]	361.30[b]	334.70[b]	284.22[b]	52.78[b]
	Disking	529.28[b]	75.61[b]	367.42[a]	342.02[a]	294.40[a]	55.62[a]
2024	Deep ploughing	585.69[a]	83.67[a]	431.40[a]	366.32[b]	304.02[b]	51.91[b]
	Disking	570.89[b]	81.56[b]	446.90[b]	390.60[a]	346.52[a]	60.70[a]

Note. Different letters within a column indicate significant differences between tillage methods (*t-test*, $p < 0.05$).

This advantage contrasts with the emergence stage, where deep ploughing, characterized by greater soil disturbance and a looser surface layer, ensured better seed coverage and more favorable conditions for germination, resulting in higher emergence rates. In comparison, the shallower tilled layer under disking led to suboptimal seed placement depth, which, under limited autumn moisture, reduced emergence (Bekele, 2020; Li et al., 2025).

However, these initial benefits of deep ploughing did not translate into higher plant survival. The deeper tilled layer (20–22 cm) retained more autumn moisture and underwent expansion during winter freezing, causing root and crown damage in some plants and leading to spring mortality. Moreover, frost heaving exposed tillering nodes, further increasing plant loss. In contrast, these adverse effects were minimal under disking due to the shallower tilled layer (Friberg et al., 2019).

Surface tillage practices have been shown to maintain or improve crop yield under certain conditions compared to conventional tillage systems (Grabovets & Fomenko, 2014; Volkov et al., 2015; Ivenin et al., 2018; Buczek et al., 2023; Dong et al., 2024; Różewicz et al., 2024), which is consistent with the results obtained in the present study (Fig. 4).

Grain and straw yields were generally higher under disking than under conventional ploughing, although the magnitude and statistical significance of these differences varied among years. In 2022, differences were not statistically significant ($p = 0.072$ and $p = 0.064$), whereas in 2023 only grain yield was significantly higher under disking ($p = 0.009$), with no significant effect on straw yield ($p = 0.695$) (Grabovets & Fomenko, 2014; Buczek et al., 2023; Dong et al., 2024; Różewicz et al., 2024).

In 2024, both grain and straw yields were significantly higher under disking. Grain yield reached 1.71 t ha^{-1} and straw yield 2.33 t ha^{-1}, exceeding the corresponding values under ploughing (1.39 and 1.92 t ha^{-1}) by 23.0% and 21.4%, respectively (Fig. 4). These differences were statistically significant for both grain ($p = 0.003$) and straw yield ($p < 0.001$), which is consistent with previous studies indicating that reduced or optimized tillage systems can maintain or improve crop yield depending on environmental conditions (Sun et al., 2022; Buczek et al., 2023).

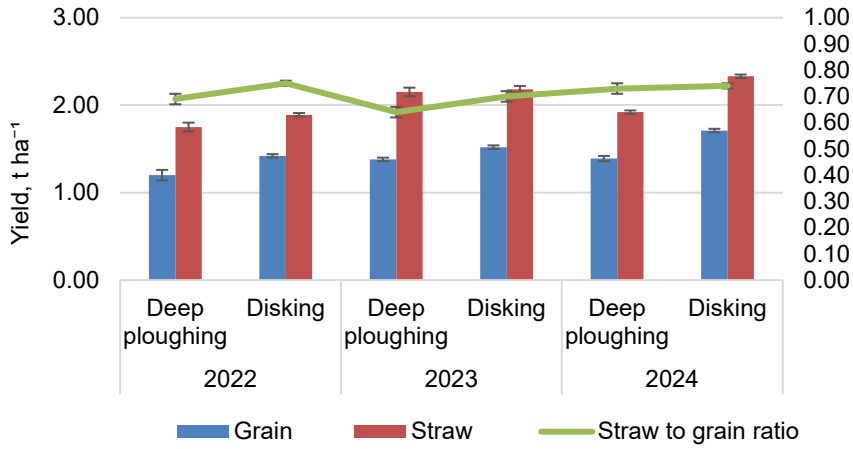

Figure 4. Effect of different tillage methods on the yield of winter wheat.
Note to the Figure. Values are presented as mean ± standard error (*SE*).

The straw-to-grain ratio was not significantly affected by tillage treatment in any of the studied years ($p > 0.05$) (Song et al., 2013; Schiere et al., 2004).

Laboratory analyses of grain quality are shown in Fig. 4. Crude protein content in 2024 was higher under ploughing ($P = 0.006$), while differences in 2022–2023 were not significant ($P > 0.05$). Crude ash content under disking was higher in all three years, but differences were not statistically significant ($P > 0.05$).

Crude fiber content in 2022 was higher under ploughing ($P = 0.006$), with no significant differences observed in 2023–2024 (Fig. 5, a). These findings are in agreement with Woźniak & Rachon (2020), who reported that tillage systems influence grain quality traits such as crude fiber, and with Aula et al. (2023), who emphasized the role of tillage practices in modifying winter wheat yield responses under variable precipitation conditions.

Total nitrogen content in wheat grains did not differ significantly among treatments ($P > 0.05$), indicating a limited effect of tillage on grain N concentration. These results are consistent with Omara et al. (2019), who reported minimal changes in total grain nitrogen under different tillage systems. Phosphorus content under disking was significantly higher in all years (2022: $P < 0.001$; 2023: $P < 0.001$; 2024: $P = 0.012$), whereas potassium content differences were not significant ($P > 0.05$) (Fig. 5, b).

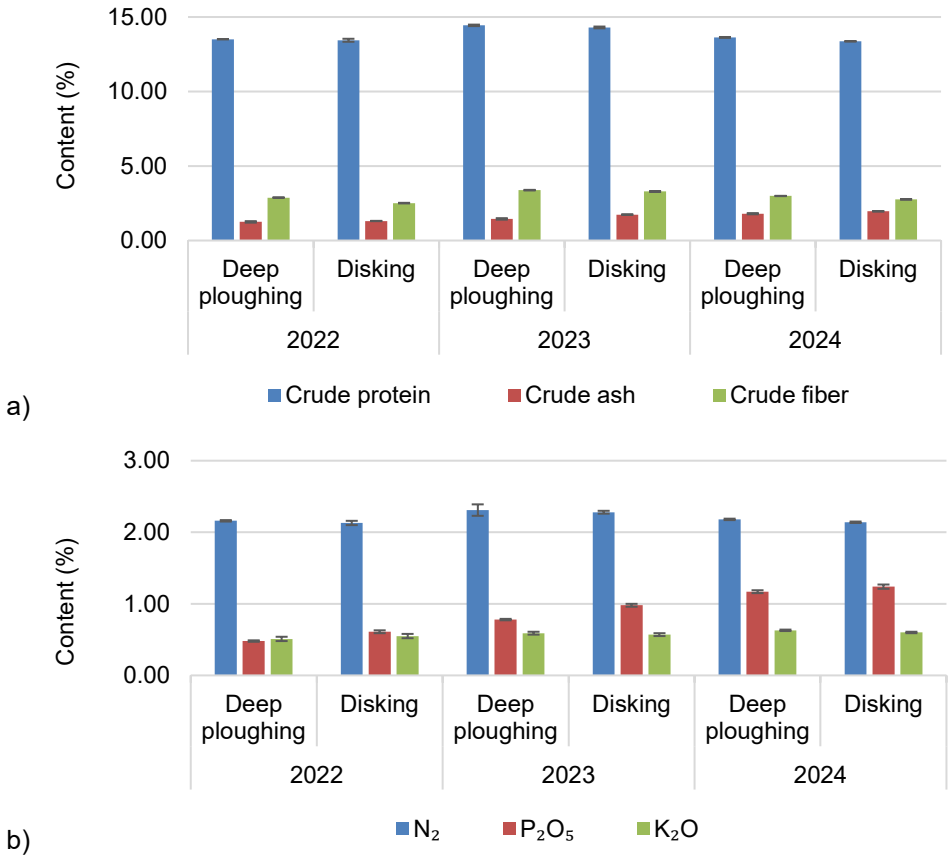

Figure 5. Mean changes in winter wheat grain composition under different tillage methods (2022–2024): (A) Crude protein, crude ash, and crude fiber; (B) Nitrogen, phosphorus, and potassium.

Note to the Figure. Values are presented as mean ± standard error (*SE*).

The results indicate that shallow tillage (disking) improved soil physical structure and nutrient availability, which in turn promoted more intensive growth, higher biomass accumulation, and enhanced yield components of winter wheat compared to conventional ploughing. These findings highlight the potential of surface tillage to maintain soil fertility and increase crop productivity under rainfed conditions. Future research should also investigate the role of soil moisture accumulation in relation to yield improvement under different tillage practices.

CONCLUSIONS

1. Shallow tillage (disking) improved soil fertility and structure, increasing humus content, water-stable aggregates, and the availability of nitrogen, phosphorus, and potassium, whereas conventional deep ploughing led to nutrient depletion and reduced organic matter in the upper soil layer.

2. Enhanced soil conditions under disking positively affected plant growth and development, resulting in higher biomass accumulation, improved yield components, and increased plant survival rates (up to 13.9% higher compared to ploughing).

3. Grain yield was significantly higher under shallow tillage, particularly in 2024, where it exceeded conventional tillage by 23.0%, demonstrating the advantage of moisture-conserving practices under rainfed conditions.

4. Grain quality components (crude protein, ash, and gluten) were significantly higher under disking in certain years, reflecting improved plant nutrition and growing conditions.

5. The results highlight the importance of adopting shallow tillage systems in mountain-steppe regions of Armenia as a sustainable approach to improve soil health and crop productivity under water-limited conditions.

6. Future research should focus on long-term effects of tillage practices on soil organic matter dynamics, biological activity, and moisture accumulation, as well as their interaction with climate variability, in order to further optimize rainfed wheat production systems.

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